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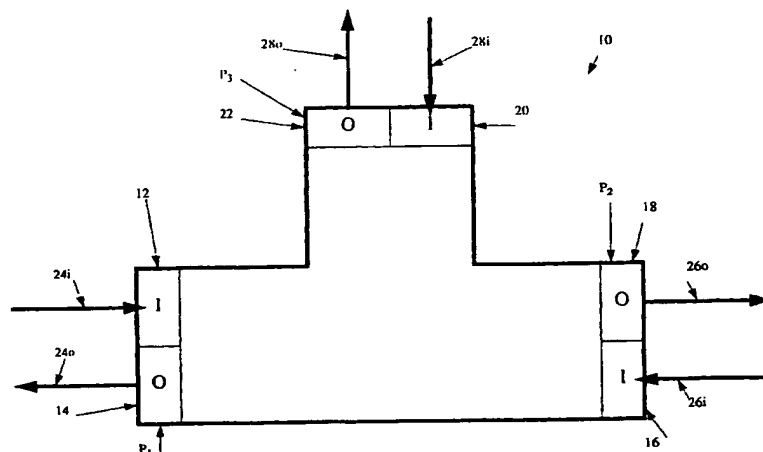
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(54) Title: A SWITCH AND A DISTRIBUTED NETWORK PROTECTION SWITCHING SYSTEM INCORPORATING SAID SWITCH



(57) Abstract: Switch (10) is provided with three ports  $P_1 - P_3$ . Port  $P_1$  has an input (12) and output (14), port  $P_2$  has an input (16) and an output (18), and port  $P_3$  has an input (20) and an output (22). Switch (10) is arranged so that a first flow presented to the input of any one of ports  $P_1 - P_3$  (eg flow 24<sub>i</sub> presented to input (12)) is delivered or internally routed to the output of an other of  $P_1 - P_3$  (eg port (18) of  $P_2$ ) and a second flow presented to the input of that other of  $P_1 - P_3$  (eg flow 26<sub>i</sub> at input (16) of port  $P_2$ ) is delivered to the output of said one of port  $P_1 - P_3$  (eg output (14) of port  $P_1$ ). A detector is included in the switch (10) for detecting a predetermined characteristic of the flow presented to the inputs of each of ports  $P_1 - P_3$ . If the detector detects the existence of a predetermined characteristic of the flow presented to input (12) or input (16) (for example at input (12)) it automatically re-routes the input of the other port (eg port (16)) to the output of the remaining port (eg output (22) of port  $P_3$ ).

# Title

## A SWITCH AND A DISTRIBUTED NETWORK PROTECTION SWITCHING SYSTEM INCORPORATING SAID SWITCH

### 5 Field of the Invention

This invention relates to a switch and a distributed network protection switching system incorporating said switch, particularly, although not exclusively, for the protection of flows through networks against the failure of channels or sites in the network.

### 10 Background of the Invention

Networks are employed to convey flows between end users. The end users may be persons, computers, other machines, biological organs or other entities which are able to transmit or receive flows. The events beyond the control of the network user cause networks to fail. Each failure within a network may disrupt one or more end users, in particular when the network is being relied upon for mission critical purposes. Network protection switching systems reduce the detrimental effects of failures upon end users. Some systems do so by switching flows away from failed parts of the network to operational parts, if any exist. The failure and the protection switching action both lead to a period of disruption to the end user. A quick protection switching response time will  
20 reduce the disruption experienced by the end users.

Throughout this specification the term "network" is used in a generic sense to describe a set of two or more sites and one or more links that connect those sites together in any topology. A network supports the end to end transfer of flows between sites across a concatenation of one or more links within that network. Each link is unidirectional, has  
25 one source end, and has one or multiple destination ends. Each link transfers a flow or flows from the source end to one or more destination ends. A flow transmitted from a site onto an operational link is transported to the destination site or sites. To form a bidirectional communication channel between two sites, links can be assembled as contra-  
30 flowing pairs.

It is important to note that the nature of the flow in one direction need not be the same as

the flow in the opposite direction. Each site is able to transmit one or more flows onto one or more links, and to receive flows from one or more links. Each link at each site is either an incoming link or an outgoing link depending on the direction of flow carried by that link. The receipt of any flow by a site from an incoming link may become unreliable while that link has failed. The transmission of a flow from a site may become unreliable when the site has failed.

Throughout this specification the word "flow" is intended to denote anything that can flow between two sites and includes the transfer of a communication, signal, substance, entity, energy, pressure, absence of pressure, vacuum, waves, particles or a group of vehicles from one site to another site or sites. A single link can carry simultaneously one or more distinct and parallel flows. A single physical medium may carry distinct and opposing links or flows. Specific examples of flows include electrical, radio or optical signals, whether in digital or analogue form that convey information between sites within the network; hydraulic pressure conveyed along tubes, pipes or hoses; gas, liquid, slurry, solids, people, other beings or organic matter; pneumatically propelled canisters; a vacuum propagated along a tube, pipe or hose; or a transfer of energy.

One of the difficulties against which network engineers and protocol architects have been struggling is that of ensuring that information about a network failure is conveyed to a prescribed site in order to initiate protection switching. The problem is to carry such information through a faulty network. It is not always straight forward to determine which part or parts of a network can be relied upon to carry this information. The information about the failures should be carried on channels or links which have not failed. Sometimes even this cannot be achieved. There have been many proposals to protect networks against failures but these all have one or more of the following disadvantages:

- They require a separate network in addition to the protected network on which to transmit fault monitoring and control signals.
- The devices which make and implement protection switching decisions are installed at sites which are geographically or topologically remote from the links or sites which they protect. In order to switch flows away from failed parts of the network, they rely

upon the transmission through that network of signals which carry information about the failure. Systems which rely upon the transmission of such fault information signals have the following disadvantages:

- It is not always possible to find a path which has not failed for the fault signals. It is thus not always possible to guarantee that the fault information signals are able to reach their destinations.
- Network users may suffer unnecessarily long disruptions because switching decisions and operations are not performed near to the points of failure and because of the time required for: i) fault signals to be generated; ii) information about a fault to be conveyed across part of a network; iii) that information to be processed; iv) protection switching decisions to be made; v) control signals to be conveyed across part of a network in order to implement switching decisions; and vi) the switching decisions to be executed.
- The network may become flooded with a large number of fault messages which may overload the network and reduce the availability of the network to the end users.
- They rely upon central sites which themselves are vulnerable to failure.
- The time required to detect that a fault has occurred may be long. The decision that a link or site has failed is delayed until after a flow has become absent for at least a specified "time-out" period, resulting in a delay before protection switching may be initiated.
- The time required for protection switching to take effect is proportional to the number of sites in a network.
- They do not protect networks whose topology is more complex than a simple point to point link.
- They require inflexible and costly non-optimal network topologies to be installed.
- They require looped or ring topology networks.
- They do not protect against the failure of sites.
- They do not permit more than one redundant link to protect each protected link.
- They do not support an arbitrary level of redundancy.
- They require redundant links to be installed where they are not required.
- In communications networks they do not operate independently of and transparently to

open systems interconnection (OSI) layer services or protocols above the physical medium dependent (PMD) sub-layer of the physical layer (layer one). Separate protection switching devices must be constructed for each type of protected network.

- They degrade network performance while a fault condition exists
- 5 • They reduce network capacity while a fault condition exists.
- They require the unnecessary duplication or replication and simultaneous transmission of flows at times when no fault exists.
- They do not co-ordinate the protection switching at each end of a failed bi-directional link.

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#### Summary of the Invention

It is an object of the present invention to provide a switch and a distributed network protection switching system that enables end to end connectivity across a network to be maintained in a highly reliable fashion by switching flows away from failed parts of the

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According to a first aspect of this invention there is provided a switch comprising at least:

first, second and third ports ( $P_1$ - $P_3$ ) each having an input and an output;

the switch arranged so that a first flow presented to the input of one of  $P_1$ - $P_3$  is

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delivered to the output of an other of  $P_1$ - $P_3$ , and a second flow presented to the input of said other of  $P_1$ - $P_3$  is delivered to the output of said one of said  $P_1$ - $P_3$ ;

detection means for detecting a predetermined characteristic of the flows presented at the input of each of  $P_1$ - $P_3$ ; and,

control means which, upon the detecting means detecting said predetermined

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characteristics in one of said first flow and said second flow, internally diverts the other of the first flow and second flow to be presented to the output of a remaining one of  $P_1$ - $P_3$ .

Preferably said switch further includes timer means for counting a time  $T$  for which the detecting means detects the existence of said predetermined characteristic of the flows and wherein said control means only diverts the other of the first and second flows to the output of said remaining one of  $P_1$ - $P_3$  when the time  $T$  is equal to or exceeds a  
5 predetermined time  $T_{wait}$ .

Preferably said switch includes a dummy flow means for producing a dummy flow and, said control means delivers said dummy flow to the output of the port to which said one of said first and second flows would be delivered in the absence of that flow being detected  
10 as having said predetermined characteristic.

In one embodiment, said predetermined characteristic is the absence of said flow for said period  $T_{wait}$ . In one embodiment, the period  $T_{wait}$  is 0.

15 In an alternate embodiment, said predetermined characteristic is a predetermined reduction in the rate of flow at said inputs. In an alternate embodiment when said flows relate to communication signals, said predetermined characteristic is a predetermined bit error rate, or signal to noise ratio.

20 In one embodiment, said dummy flow means is in the form of a generator for generating a flow of the same type as the flow presented to the inputs of said switch.

In an alternate embodiment, said dummy flow means includes means for sampling and subsequently replicating the flow presented to the inputs of the switch.

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Preferably said detection means is further able to detect the absence of said predetermined characteristic after said control means has internally diverted said other of the first flow and second flow to the output of the remaining one of  $P_1$ - $P_3$ , whereup said control means rediverts said other of the first flow and second flow to be presented to the output of the  
30 other or one of  $P_1$ - $P_3$ , as the case may be.

According to a further aspect of the present invention there is provided a method of using and operating a switch having first, second and third ports ( $P_1$ -  $P_3$ ), each port having an input and an output, said method comprising the steps of :

- coupling an incoming first flow of a first channel to the input of one of  $P_1$ - $P_3$ ;
- internally routing said incoming first flow to the output of an other of  $P_1$ - $P_3$ ;
- 5     coupling an incoming second flow of a second channel to the input of said other of said  $P_1$ - $P_3$ ;
- internally routing said incoming second flow to the output of said one of said  $P_1$ - $P_3$ ;
- monitoring said inputs to detect a predetermined characteristic of the flow at said
- 10    inputs;
- upon detecting said predetermined characteristic in one of said first flow and said second flow, internally re-routing the other of the first flow and the second flow to the output of a remaining one of the ports  $P_1$ - $P_3$ .

- 15    Preferably said method further includes a step of counting a time  $T$  for which said predetermined characteristic is detected and wherein said step internally of re-routing only occurs if said time  $T$  is equal to or exceeds a predetermined time  $T_{wait}$ .

- 20    Preferably said method further includes a step of generating a dummy flow and internally routing said dummy flow to the output of the port to which said one of said first and second flow would be delivered in the absence of that flow being detected as having said predetermined characteristic.

- 25    According to a further aspect of the present invention there is provided a network having a distributed network protection switching system the network comprising at least:

- first and second sites ( $X_1$ ,  $X_2$ ) for transmitting and receiving one or more flows;
- a first channel to allow bidirectional transfer of flows between said sites;
- at least one further channel to provide an alternate route for bidirectional transfer of flows between said sites, each of said first channel and said at least one further channel
- 30    having a unidirectional incoming link and a unidirectional outgoing link;
- a first switch ( $S_1$ ) and a second switch ( $S_2$ ), each of  $S_1$ , and  $S_2$  being in accordance with the first aspect of this invention;

S<sub>1</sub> coupled to the first site (X<sub>1</sub>) so that a flow out of X<sub>1</sub> is presented to the input of any one of P<sub>1</sub>-P<sub>3</sub> of S<sub>1</sub> and a flow into X<sub>1</sub> is delivered from the output of said one of P<sub>1</sub>-P<sub>3</sub> of S<sub>1</sub>;

S<sub>2</sub> coupled to X<sub>2</sub> so that a flow out of X<sub>2</sub> is presented to the input of any one of P<sub>1</sub>-P<sub>3</sub> of S<sub>2</sub> and a flow into X<sub>2</sub> is delivered from the output of said one of P<sub>1</sub>-P<sub>3</sub> of S<sub>2</sub>;

the outgoing link of channel C<sub>1</sub>, viewed from X<sub>1</sub>, connected between the output of an other of P<sub>1</sub>-P<sub>3</sub> of switch S<sub>1</sub> and the input of an other of P<sub>1</sub>-P<sub>3</sub> of switch S<sub>2</sub>;

the incoming link of channel C<sub>1</sub>, viewed from site X<sub>1</sub>, connected between the input of said other of P<sub>1</sub>-P<sub>3</sub> of switch S<sub>1</sub> and the output of said other of P<sub>1</sub>-P<sub>3</sub> of switch S<sub>2</sub>;

the outgoing link of channel C<sub>2</sub>, viewed from site X<sub>1</sub>, connected between the output of the remaining one of P<sub>1</sub>-P<sub>3</sub> of switch S<sub>1</sub> and the input of the remaining one of P<sub>1</sub>-P<sub>3</sub> of switch S<sub>2</sub> and, the incoming link of channel C<sub>2</sub> viewed from site X<sub>1</sub> being connected between the input of the remaining one of ports P<sub>1</sub>-P<sub>3</sub> of switch S<sub>1</sub> and the output of the remaining one of P<sub>1</sub>-P<sub>3</sub> of switch S<sub>2</sub>;

whereby, in use, upon said detection means of one of S<sub>1</sub> and S<sub>2</sub> detecting a predetermined characteristic of a flow presented at its input from channel C<sub>1</sub>, said one of S<sub>1</sub> and S<sub>2</sub> internally diverts the flow directed to the output of the port containing that input to the output of the remaining port thereby causing the detection means of the other one of S<sub>1</sub> and S<sub>2</sub> to detect the absence of a flow at the input of the other one of switches S<sub>1</sub> and S<sub>2</sub> from channel C<sub>1</sub> so that the flow delivered to the output of the other port of switch S<sub>2</sub> is directed to the output of the remaining port of switch S<sub>2</sub> thereby switching the channel of communication between the first and second sites X<sub>1</sub>,X<sub>2</sub> from channel C<sub>1</sub> to channel C<sub>2</sub>.

## Brief Description of the Drawings

Embodiments of the present invention will now be described in detail with reference to the accompanying drawings in which:

Figure 1 is a block diagram of a switch in accordance with an embodiment of the present invention;

Figures 2A, 2B & 2C depict three internal switching configurations of the switch shown in Figure 1;



- Figure 3 is a block diagram of the switch depicted in Figure 1;  
Figures 4-14 depict the switching configurations employed in 11 different states of one state machine used to describe the operation of the switch shown in Figure 1;
- 5 Figure 15 illustrates an embodiment of one network incorporating the switch and distributed network protection switching system in accordance with the present invention;
- Figure 16 illustrates a distributed network protection switching system for protecting a network against a site failure;
- 10 Figure 17 illustrates a distributed network protection switching system for protecting a network against a point to point channel failure;
- Figure 18 illustrates a distributed network protection switching system for protecting a network against a link failure between switches in the network;
- 15 Figure 19 illustrates on possible set of timing relationships in the operation of the switch;
- Figure 20 depicts a bypass device that can be incorporated in or associated with the switch; and
- Figure 21 is a block diagram of a further embodiment of the switch.

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#### Detailed Description of the Preferred Embodiments

Referring to the accompanying drawings, switch 10 in accordance with an embodiment of this invention is provided with three ports  $P_1$ - $P_3$ . Each port has an input I and an output O. The input of port 1 ( $IP_1$ ) and the output of port 1 ( $OP_1$ ) are designated by reference

25 numbers 12 and 14 respectively. Similarly  $IP_2$ ,  $OP_2$ ,  $IP_3$ ,  $OP_3$ , are designated as reference numerals 16, 18, 20 and 22 respectively. The switch 10 has three incoming links 24i, 26i and 28i for presenting flows to the inputs 12, 16, and 20 respectively and three outgoing links 24o, 26o, and 28o for carrying flows delivered from the outputs 14, 18 and 22 respectively. The pairs of links at each port can be considered to form a bidirectional

30 channels 24, 26 and 28.

The switch 10 is arranged so that a first flow presented to the input of any one of ports  $P_1$ -

$P_3$  (for example a flow on link 24i to input 12) is delivered to the output of an other of  $P_1$ - $P_3$  (for example output 18 of port  $P_2$ ) and a second flow presented to the input 1 of that other of  $P_1$ - $P_3$  (ie in this case the flow on link 26i to the input 16 of port  $P_2$ ) is delivered to the output O of said one of ports  $P_1$ - $P_3$  (ie output 14 of port  $P_1$ ). Thus, the channel 24 is  
5 connected to the channel 26 via internal paths in switch 10 connecting input 12 to output 18, and input 16 to output 14.

Detection means (not shown in Figure 1) is included in the switch 10 for detecting a predetermined characteristic of the flows presented to the inputs of each of the ports  $P_1$ - $P_3$ .  
10 Associated with the detection means is a control means (not shown in Figure 1) that, upon the detecting means detecting the predetermined characteristic in one of the flows presented to the inputs 12 or 16 internally diverts the flow from the other one of these inputs to the output 22 of the remaining port  $P_3$ .

15 Depending on the state of the switch 10, flows through the switch 10 can be passed through different combinations of pairs of ports  $P_1$ - $P_3$ . Figure 2A illustrates the switch 10 in a configuration where flows pass through ports  $P_1$  and  $P_2$  of the switch 10. In Figure 2B, the flows are directed through ports  $P_1$  and  $P_3$ ; and in Figure 2C the flows are directed through ports  $P_2$  and  $P_3$ . The configuration taken by the switch 10 is dependent upon the  
20 characteristics detected at each of the inputs of all three ports as well as the current state of the switch 10.

Referring to Figure 3, the switch 10 is provided with flow detectors 30, 32 and 34 connected with the inputs 12, 16 and 20 respectively for detecting a predetermined  
25 characteristic of the flows presented to those inputs by the incoming links 24i, 26i and 28i. As explained in greater detail hereinafter, the predetermined characteristic may be the simple presence or absence of a flow, or a predetermined bit error rate (for a digital transmission) or a signal to noise ratio (for an analogue transmission). However for the purpose of the following discussion, the detectors 30, 32 and 34 are structured to detect the  
30 present or absence of the flow, including a dummy flow, at each of the incoming links 24i, 26i and 28i. The presence of a flow is interpreted as "link healthy". The absence of a flow for greater than a time  $T_{\text{detect}}$  ( $T_{\text{detect}}$  is described below) is interpreted as "link not healthy"

or "link failed". Each of the detectors 30, 32 and 34 is coupled by a corresponding line to a controller 36. The flow on incoming link 24i is passed to internal switch 38 for directing the flow along one of alternate paths 40,42. The flow on incoming path 26i can be switched via internal switch 44 along alternate paths 46,48. The flow on incoming line 28i is provided to switch 50 for switching between alternate paths 52 and 54. The switch 10 includes internal output switch 56 leading to output 14; output switch 58 leading to output 18; and output switch 60 leading to output 22. Switch 10 further includes a dummy signal means 62 for generating a dummy flow or sampling and replicating a flow on one of the incoming links 24i, 26i, 28i. The output of the dummy generator is presented to switch 64. The switch 64 is linked to switch 60 by path 66, linked to switch 56 by path 68, and linked to switch 58 by path 70. Each of the switches 38, 44, 50, 56, 58, 60 and 64 has an associated control block 72. Each control block 72 receives control signals from the controller 36 via respective signal lines 74.

Also included is a power supply block 76 for providing a regulated power supply to the internal components of switch 10.

The purpose of the dummy flow produced by the dummy generator 62 is to enable one or more switches 10 elsewhere in the network to detect the presence of that dummy flow and to interpret the detection of that flow as "incoming link healthy". A dummy flow from one switch 10 is able to stimulate switching decisions at another switch 10. The requirements of the dummy flow and the dummy flow source which generated are not stringent. For example, in an optical embodiment of the switch 10, a continuous stream of light of suitable wavelength would suffice as a dummy flow. Where optical receiver power specifications or safety requirements are to be met (for example to avoid eye damage) a low duty cycle rectangular wave form would be employed to reduce the transmitted optical power. In an electrical embodiment, a simple square wave or rectangular wave would suffice. Where a periodic wave form is used the longest off period should be less than a predetermined time  $T_{\text{detect}}$ .

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Optionally, instead of generating a dummy flow, in another embodiment of the invention the dummy flow means would replicate a selected incoming flow so that a copy of that

incoming flow could be transmitted onto one or more selected outgoing links.

- 5 The controller 36 monitors the presence or absence of flows detected at each of the incoming links 24i, 26i and 28i via corresponding flow detectors 30, 32 and 34. In this configuration it can be seen that the flow on incoming link 24i can be delivered to the output 18 via switch 38, path 40 and switch 58; or output 22 via switch 38, path 42, and switch 60. The flow at input 16 carried on incoming line 26i can be delivered to the output 14 via switch 44, path 46 and switch 56; or output 22 via switch 44, path 48 and switch 60. A flow incoming on line 28i at input 20 can be delivered to the output 14 via switch 50, path 52 and switch 56; or to the output 18 via switch 50, path 54 and switch 58.
- 10 The dummy flow provided by dummy generator 62 can be delivered to output 14 via switch 64, path 68 and switch 56; to output 18 via switch 64, path 70 and switch 58 or to output 22 via switch 64, path 66 and switch 60.
- 15 By supplying the appropriate combination of control signals to these internal switches, the controller 36 is able to cause a flow presented at the input of one port to be directed to the output to either one of the remaining ports. The controller 36 is also able to cause the dummy flow to be switched to any one of the three output ports, 14, 18 and 22. Additionally, the controller 36 is able to sense whether adequate power supply is available from the power supply box 76. In the absence of adequate power, or if no flow is detected
- 20 on both normal incoming links 24i and 26i, the control block 36 activates two nominal normal paths to allow a flow presented at input 12 to flow to output 18 and a flow presented at input 16 to flow to output 14.
- 25 It is possible to implement the controller 36, dummy flow generator 62 and switches 38, 44, 50, 56, 58, 60 and 64 in a field programmable gate array (FPGA) such as the **ALTERA** EPF8282V which performs a switching algorithm based on a state machine described hereinafter. The input and output at each port can be realised by the use of a transceiver such as the Crystal Technologies CS61304A T1E1 line interface. This would
- 30 provide signal bit rates at 1.544Mbps and 2.048Mbps. This component extracts bit clock and line data from an incoming flow, and generates a "loss of signal" (LOS) output signal when the absence of an incoming flow is detected. The data, clock and LOS outputs are

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supplied to the FPGA. A local timing source can be provided by a crystal such as the 32.768Mhz FOX F5C HS oscillator. The FPGA generates a dummy flow derived from the local clock and in accordance with the state machine (to be described below). Incoming and dummy data and clock signals are supplied from the FPGA to the line  
5 interfaces which transmit them to the outgoing links. Local and remote management interfaces enable the switch 10 to provide status information and to be controlled.

The operation of the switch 10 may be specified by a state machine. Figures 4-14 illustrate the 11 possible states in which the switch 10 would be found.

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The 11 states are: OFF (O); NORMAL (N); IDLE (I); WAIT A (WA); WAIT B (WB); SKEW A (SA); SKEW B (SB); LOCK A (LA); LOCK B (LB); HUNT A (HA); and HUNT B (HB). Each is described below.

#### 15 OFF (O) (Figure 4)

No power is supplied to the switch 10. If a by-pass device is installed it operates to by-pass the switch 10. Each of inputs 12 and 16 is through enabled if possible to outputs 18 and 14 respectively. The broken lines represent that. Any flows which might be present at links 24i and 26i are thus transmitted to links 26o and 24o respectively. The switch 10  
20 remains in the OFF state until power is supplied to it. It does not perform any active functions. Should power be applied the switch 10 switches to one of the other ten states whose descriptions follow below. The switching decision is not affected by the presence or the absence or nature of any flow at 28i, 24i or 26i. No flow is transmitted from 28o. No dummy flow is transmitted.

25

#### NORMAL (N) (Figure 5)

A flow is detected at inputs 12 and 16 for incoming links 24i and 26i. The switch 10 is through enabled. Each flow from incoming links 24i and 26i is transmitted onto the normal outgoing links 26o and 24o respectively via outputs 18 and 14. The switching  
30 decision is not affected by the presence or absence or nature of any flow on link 28i. No flow is transmitted from output 22 onto link 28o. No dummy flow is transmitted.

IDLE (I) (Figure 6)

No flow is detected at either inputs 12 or 16 for links 24i or 26i. The switch 10 is through enabled. No flows are transmitted from outputs 14 or 18 onto links 24o or 26o. The switching decision is not affected by the presence or absence or nature of any flow presented to input 20 on link 28i. No flow is transmitted from output 22 onto link 28o.  
No dummy flow is transmitted.

WAIT A (WA) (Figure 7)

No flow is detected at input 16 for link 26i. A flow is detected at input 12 on link 24i. Link 24i is through enabled so that any flow at link 24i is transmitted from link 26o. The dummy flow 62 is active and transmitted from 24o. A timer TB is timing the delay period  $T_{WAIT}$ . ( $T_{WAIT}$  is described below.) The switching decision is not affected by the presence or absence or nature of any flow at link 28i. No flow is transmitted from link 28o.

WAIT B (WB) (Figure 8)

No flow is detected at input 12 for link 24i. A flow is detected at input 16 on link 26i. The flow on link 26i is through enabled to be delivered to output 14 and thus be transmitted on link 24o. The dummy flow 62 is active and delivered to output 18 to flow on link 26o. A timer TA is timing the delay period  $T_{WAIT}$ . ( $T_{WAIT}$  is described below.) The switch 10 is not affected by the presence or absence or nature of any flow on link 28i. No flow is transmitted from 28o.

SKEW A (SA) (Figure 9)

A flow on link 24i is detected at input 12. No flow is detected at input 16 for link 26i. The link 24i flow is delivered to output 22 to be transmitted on the alternative outgoing link 28o. The dummy flow 62 is active and delivered to output 14 to be transmitted on link 24o. No flow is transmitted on link 26o.

SKEW B (SB) (Figure 10)

A flow on link 26i is detected at input 16. No flow is detected at input 12 for link 24i. The link 26i flow is delivered to output 22 to be transmitted on alternative outgoing link 28o. The dummy flow 62 is active and transmitted from link 26o. No flow is transmitted

from link 24o.

#### LOCK A (LA) (Figure 11)

- 5 A flow is detected at each of inputs 12 and 20 for incoming links 24i and 28i. No flow is detected at input 16 for link 26i. The incoming flow from link 24i is transmitted onto link 28o. The incoming flow from link 28i is transmitted onto link 24o. No flow is transmitted from link 26o. No dummy flow is transmitted.

#### LOCK B (LB) (Figure 12)

- 10 A flow is detected at each of the inputs 16 and 20 of incoming links 26i and 28i. No flow is detected at input 12 for link 24i. The incoming flow from link 26i is transmitted onto link 28o. The incoming flow from link 28i is transmitted onto link 26o. No flow is transmitted from link 24o. No dummy flow is transmitted.

#### HUNT A (HA) (Figure 13)

- 15 No flow is detected at input 16 for link 26i. A flow is detected on link 24i. The flow received on link 24i is through enabled and transmitted from link 26o. The dummy flow 62 is active and transmitted from link 28o. No flow is detected at link 28i. No flow is transmitted from link 24o.

20

#### HUNT B (HB) (Figure 14)

- No flow is detected at input 12 for link 24i. A flow is detected on link 26i. The flow received on link 26i is through enabled and transmitted from link 24o. The dummy flow 62 is active and transmitted from link 28o. No flow is detected at link 28i. No flow is transmitted from link 26o.
- 25

Transitions between the above described states are caused by the following events:

- |    |                 |  |   |
|----|-----------------|--|---|
| E1 | <b>Power On</b> | The switch 10 commences to receive an adequate power supply. |   |
| 30 | E2              | <b>A Found</b>   | A flow is detected at link 24i.           |
|    | E3              | <b>A Lost</b>  | A flow at link 24i ceases to be detected. |
|    | E4              | <b>B Found</b>   | A flow is detected at link 26i.           |

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	E5 B Lost	A flow at link 26i ceases to be detected.
	E6 Alt Found	A flow is detected at link 28i.
	E7 Alt Lost	A flow at link 28i ceases to be detected.
	E9 TA Timeout	The $T_{WAIT}$ timer T expires.
5	E11 TB Timeout	The $T_{WAIT}$ timer T expires.
	E12 Power Off	The switch 10 ceases to receive an adequate power supply. The switch 10 returns to the OFF state after this event, irrespective of any prior state.

- 10 The algorithm implemented at each switch 10, and the set of states, events and transitions between states which are employed here to describe the invention are not unique. The invention may be performed with alternative state machines and algorithms. Some state machines may employ a different number of state transitions than described here. For example the invention may also be performed using the state machine described here and
- 15 with the following additional state transitions: IDLE to NORMAL; WAIT A to LOCK A; and WAIT B to LOCK B.

The switch 10 contains two delay timer functions TA and TB. TA is activated when the event "A Lost" occurs; TB is activated when the event "B Lost" occurs. Both TA and TB

20 are configured to measure the delay time  $T_{WAIT}$ . Expiry of the timer TA after delay  $T_{WAIT}$  causes the switch 10 to switch from the WAIT B state to the SKEW B state. Expiry of the timer TB causes the switch 10 to switch from the WAIT A state to the SKEW A state. While the switch 10 is in the WAIT A state, if the flow at link 24i is also subsequently lost the switch 10 remains in the WAIT A state until either: the timer TB expires; or the flow

25 at link 26i is newly detected.

Optionally, the delay time  $T_{WAIT}$  may be set to zero in some switches 10. In such cases the transition through the WAIT states will be instantaneous.

- 30 Optionally, the TA delay time  $T_{WAIT}$  may be set to a different value from the TB delay time  $T_{WAIT}$ .



One switch 10 state transition table is shown in table one below. While the switch is in any of the states shown at the left of the table, the occurrence of any of the events shown at the top of the table causes the switch 10 to change to the new state shown within the table.

The Power On event only occurs while in the OFF state and is the only event possible in the OFF state.

Present State ↓	Events									
	E1 Power On	E2 A Found	E3 A Lost	E4 B Found	E5 B Lost	E6 Alt Found	E7 Alt Lost	E9 TA Timeout	E11 TB Timeout	E12 Power Off
OFF	I									
I		HA		HB		I	I			OFF
HA			I	N		LA				OFF
HB		N			I	LB				OFF
N			WB		WA	N	N			OFF
WA		WA	WA	N		WA	WA		SA	OFF
WB		N		WB	WB	WB	WB	SB		OFF
SA			I	N		LA				OFF
SB		N			I	LB				OFF
LA			I	N			SA			OFF
LB		N			I		SB			OFF

Table 1: Network Repair Module State Transitions

- 10 Figure 21 illustrates a further embodiment of the switch 10' in which like reference numbers are used to denote like features. In short, the switch 10' includes various features in addition to those of the switch 10 depicted in Figures 1 and 3. Most notably, the switch 10' is provided with a fourth port P<sub>4</sub>. Port P<sub>4</sub> has an input 140 and an output 142 to facilitate coupling with an ingoing link 144i and an outgoing link 144o. The input 140 and output 142 communicate via paths 146 and 148 respectively with the controller 36.
- 15 The main purpose of port P<sub>4</sub> is to allow external communication with and control of the

switch 10'. For example control can be exerted on the switch 10' via a signal input and link 144i instructing the controller 36 to force the switch 10' to change from one state to another.

5 The switch 10' also includes a status signal generator 150 which is shown in Figure 3 as a portion of a controller 36. However the status signal generator may also be incorporated in the detectors 30, 32 and 34 with a switch 10 or indeed be distributed between the controller 36 and the detectors 30, 32 and 34. The status signal generator 150 monitors the state of the switch and its operational status. The status signal generated by the generator  
10 150 can be communicated to an external controller or control panel either via channel 148, output port 142 and link 144o or via the output of any one of the other ports  $P_1$ - $P_3$ . When the status signal is communicated via port  $P_4$ , the outgoing link 144o will carry only the status signal. However the controller 36 or indeed other parts of the switch 10' can be programmed, hardwired, or otherwise arranged so as to add or embed the status signal  
15 onto a flow which is outgoing from one of the outputs of ports  $P_1$ - $P_3$ . For example, if the switch 10' is operating in a SONET network the signal generator 150 can operate to change the state of one or more bits in the SONET line, section or path overhead fields to provide status information. On the other hand, if the switch 10' is operating so in a water reticulation or distribution system, signal generator 150 may act to add a dye to the water  
20 to provide information regarding the status of the switch and the flows it receives.

The status signal generator 150 can also act as or include a report flow generator to communicate with external entities the status of the switch 10'. The external entities may be other switches 10 or other devices. The report flow generator would generate a report  
25 flow when a predetermined characteristic of a flow is detected in any one or more of the inputs of ports  $P_1$ - $P_3$ . The nature of the report flow is such that it would be possible for an external entity to determine from the report flow the complete and exact status of the switch 10' including, for each of ports  $P_1$ - $P_3$ , whether the predetermined characteristic is present or absent. As with the status signal, the report flow would be delivered under the  
30 control of the controller 36 to any one or more of the outputs of ports  $P_1$ - $P_4$ .

The interaction between switches 10 and the operation of the state machine at each switch

10 is now described in detail by way of example. Two cases are examined: link failure; and site failure.

Figure 15 shows nine switches  $10_A-10_I$  that are arranged to protect a bidirectional channel  $C_1$  comprising a pair of links marked 78 in one direction and 80 in the opposite direction. The links 78 and 80 through switches  $10_A-10_D$  form the normal channel which would be used when there are no faults. There are two redundant paths or channels: the first redundant channel  $C_2$  comprises links 82,84 through switches  $10_E-10_G$ ; and the second redundant channel  $C_3$  comprises links 86 and 88 through switches  $10_H$  and  $10_I$ . The switches  $10_A$  and  $10_B$  would be at one site and the Switches  $10_C$  and  $10_D$  would be at a separate site.

The sequence of states in which each switch 10 finds itself during protection switching after a link failure is shown in Table 2 below. The description and the table illustrate only one of many possible sequences of state transitions which may occur as a result of the failure. The description and the Table do not illustrate all state changes which may occur.

Switches  $10_A-10_D$  each commence in the NORMAL state (N) and carry flows along links 78,80. No flow is carried on the redundant channels  $C_2, C_3$  and Switches  $10_E-10_I$  commence in the IDLE state (I).

Let a failure occur in channel  $C_1$  between switches  $10_B$  and  $10_C$ . It does not matter whether the failure occurs only on a single link 78 or 80, or on both links 78 and 80, or if there is a time delay between a failure on each; the present invention will operate in all cases. In this example we shall assume that the failure occurs either on link 80 only, or on both links 78 and 80. The failure causes switch  $10_B$  to detect the absence of a flow at its input 16, where the flow from switch  $10_C$  via link 80 normally would be received. The absence of that flow causes switch  $10_B$  to enter the WAIT A state (WA) and to present a dummy flow to its output 14 onto link 80 towards switch  $10_A$ . The dummy flow is detected by switch  $10_A$  and further downstream on link 80. If for some reason the link is repaired and the incoming flow on link 80 at input 16 of switch  $10_B$  is again detected then switch  $10_B$  returns to the NORMAL state. However, if the flow remains absent for at least

a time  $T_{WAIT}$  (which would cause the timer TB to expire and the TB Timeout event to occur) then switch  $10_B$  enters the SKEW A state (SA), where it ceases to deliver any flow to output 18 and thus link 78 ceases to transmit any flow towards switch  $10_C$ . Instead, the incoming flow at input 12 of switch  $10_B$  is switched onto the alternative outgoing link 82 via its output 22 and travels towards switch  $10_E$ .

Switch	$10_A$	$10_B$	$10_C$	$10_D$	$10_E$	$10_F$	$10_G$	$10_H$	$10_I$
Initial State	N	N	N	N	I	I	I	I	I
After failure	N	WA	N	N	I	I	I	I	I
After $T_{WAIT}$ at $10_B$	N	SA	N	N	I	I	I	I	I
Flow link 82 reaches $10_E$	N	SA	N	N	HA	I	I	I	I
Flow link 82 reaches $10_F$	N	SA	N	N	HA	HA	I	I	I
Flow link 82 reaches $10_G$	N	SA	N	N	HA	HA	HA	I	I
Loss detected at $10_C$	N	SA	WB	N	HA	HA	HA	I	I
After $T_{WAIT}$ at $10_C$	N	SA	SB	N	HA	HA	HA	I	I
Flow link 84 reaches $10_G$	N	SA	SB	N	HA	HA	N	I	I
Flow link 84 reaches $10_F$	N	SA	SB	N	HA	N	N	I	I
Flow link 84 reaches $10_E$	N	SA	SB	N	N	N	N	I	I
Flow link 84 reaches $10_B$	N	LA	SB	N	N	N	N	I	I
Flow link 82 reaches $10_C$	N	LA	LB	N	N	N	N	I	I
Final state	N	LA	LB	N	N	N	N	I	I

Table 2: Summary of Significant State Transitions in Response to Link Failure.

- Note 1: The sequence of transitions shown above is only one of many valid possible sequences.  
 Note 2: No time scale is implied by Table 2.

Switch  $10_E$  in the IDLE state, detects at its input 12 via link 82 the flow from output 22 of switch  $10_B$ . That event causes switch  $10_E$  to enter the HUNT A state (HA) in which it:  
 i) delivers a dummy flow to its  $P_3$  output 22; and ii) transmits the incoming flow it receives at its input 12 onto link 82 via its  $P_2$  output 18. Switches  $10_F$  and  $10_G$  subsequently change from the IDLE state to the HUNT A state as a result of detecting the flow propagated to them along link 82 from switch  $10_B$ .

After the disappearance of the flow on link 78 and thus at input 12 of  $P_1$  of switch  $10_C$ , switch  $10_C$  enters the WAIT B state (WB) and then after a time delay  $T_{WAIT}$  enters the SKEW B state (SB) if it has not yet detected any flow at input 20 of  $P_3$  via link 82. A

dummy flow is transmitted by switch  $10_C$  downstream along link 78 to switch  $10_D$  and beyond. In the SKEW B state the incoming flow on link 80 at input 16 of  $P_2$  of switch  $10_C$  is switched to output 22 of  $P_3(10_C)$ . After travelling along link 84 that flow is detected at input 16  $P_2(10_G)$ . Switch  $10_G$  then either: if no flow is detected at input 12,  $P_1(10_G)$ , changes from the IDLE state to the HUNT B state (HB); or, (as shown in Table 2) if it has already detected a flow at input 12,  $P_1(10_G)$ , changes from the HUNT A state to the NORMAL state. Eventually switch  $10_G$  detects a flow at both input 12,  $P_1$  and input 16,  $P_2$  and enters the NORMAL state. The flow from output 14,  $P_1(10_G)$  propagates further downstream along link 84 through switches  $10_F$  and  $10_E$  in that order, eventually causing these switches to switch into the NORMAL state.

The flow from switch  $10_C$  via link 84 and switches  $10_G$ ,  $10_F$ ,  $10_E$  is detected at input 20,  $P_3$  of switch  $10_B$ . That event causes switch  $10_B$  to change from the SKEW A state to the LOCK A state (LA). The flow propagated along the link 82 from switch  $10_G$  causes switch  $10_C$  to change from the SKEW B state to the LOCK B state (LB) when it detects the flow at input 20,  $P_3$ . A complete bidirectional channel  $C_2$  via switches  $10_A$ ,  $10_B$ ,  $10_E$ ,  $10_F$ ,  $10_G$ ,  $10_C$  and  $10_D$  now operates around the failed normal channel  $C_1$ . A subsequent failure of the redundant links 82 or 84 in channel  $C_2$  causes a similar sequence of events and state changes at switches  $10_A$ ,  $10_H$ ,  $10_I$  and  $10_D$  which result in diversion of flows along channel  $C_3$  via switches  $10_A$ ,  $10_H$ ,  $10_I$  and  $10_D$ . An arbitrary level of redundancy may be achieved by recursively nesting protection channels and switches.

Figure 16 shows nine switches  $10_A$ - $10_I$  that are arranged to protect a network against the failure of a site 90. Site 90 contains a set of one or more nodes 92 and two switches  $10_B$ ,  $10_C$ . Table 3 shows the sequence of states after the failure or removal of site 90. Switches  $10_A$ - $10_D$  commence in the NORMAL state (N), and switches  $10_E$ - $10_I$  commence in the IDLE state (I). Site 90 is constructed in such a manner that any failure at site 90 causes all the flows from site 90 to cease being transmitted. If site 90 fails no flows are transmitted on any of the four outgoing links 11, 13, 15 and 17 which emanate from site 90. Switch  $10_A$  detects the loss of flow at its input 16 and switch  $10_D$  detects the loss of flow at its input 12. The switch  $10_A$  changes from the NORMAL state to the WAIT A state (WA) and switch  $10_D$  changes from the NORMAL state to the WAIT B state (WB).

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Dummy flows are transmitted separately by switch 10<sub>A</sub> onto link 19 and by switch 10<sub>D</sub> onto link 21.

After a time delay  $T_{\text{WAIT}}$  at switch 10<sub>A</sub>, this switch enters the SKEW A (SA) state. After a  
5 time delay  $T_{\text{WAIT}}$  at switch 10<sub>D</sub>, this switch enters the SKEW B (SB) state. The flow on  
incoming link 23 to switch 10<sub>A</sub> is transmitted onto link 25 coupled to output 22 of switch  
10<sub>A</sub>; and the flow on incoming link 27 to switch 10<sub>D</sub> is transmitted onto link 29 coupled to  
output 22 of switch 10<sub>D</sub>. Switches 10<sub>E</sub>, 10<sub>F</sub>, 10<sub>G</sub> switch in that sequence from the IDLE  
10 state to the HUNT A state (HA) as the flow is propagated along the link 25 from switch  
10<sub>A</sub>. Similarly, as the flow from output 22 of switch 10<sub>D</sub> is propagated along link 29,  
switches 10<sub>I</sub>, 10<sub>H</sub> change from the IDLE state to the HUNT B state (HB) in that sequence.  
It is a combination of both the topology shown and the switching algorithms that ensures  
that switches 10<sub>G</sub> and 10<sub>H</sub> make contact and receive flows from each other.

15 When switch 10<sub>G</sub> detects the flow at its input 20 from link 31, it changes from the  
HUNT A state to the LOCK A state (LA). Switch 10<sub>G</sub> detects flows at input 12 from link  
25 and at input 20 from link 31. When switch 10<sub>H</sub> detects the flow on link 33 from switch  
10<sub>G</sub> at input 20 it changes from the HUNT B state to the LOCK B state (LB). The flow  
received by switch 10<sub>G</sub> at its input 20 is switched onto its output 14 and propagated on link  
20 35 via switches 10<sub>F</sub> and 10<sub>E</sub> to switch 10<sub>A</sub>. That flow causes switches 10<sub>F</sub> and 10<sub>E</sub> each to  
change from the HUNT A state to the NORMAL state in that sequence. When the flow is  
detected at input 20 of switch 10<sub>A</sub>, that switch changes from the SKEW A state to the  
LOCK A state. Similarly, the flow received by switch 10<sub>H</sub> at its input 20 is switched onto  
its output 18 and propagated by link 17 to switch 10<sub>D</sub> via switch 10<sub>I</sub>. That causes switch  
25 10<sub>I</sub> to change from the HUNT B state to the NORMAL state. When the flow is detected at  
input 20 of switch 10<sub>D</sub>, that switch changes from the SKEW B state to the LOCK B state.

The switches have now constructed a bidirectional channel around site 90 via switches  
10<sub>A</sub>, 10<sub>E</sub>, 10<sub>F</sub>, 10<sub>G</sub>, 10<sub>H</sub>, 10<sub>I</sub> and 10<sub>D</sub>. The flow on incoming link 23 to input 12 of switch  
30 10<sub>A</sub> is carried via links 25, 33 and 17 to switch 10<sub>D</sub> and is transmitted by switch 10<sub>D</sub> onto  
link 21. The flow on incoming link 27 presented to input 16 of switch 10<sub>D</sub> is carried via  
links 29, 31 and 35 to switch 10<sub>A</sub> and is delivered by switch 10<sub>A</sub> onto its output 14 to flow

on outgoing link 19. The failed site 90 is thus by-passed.

Switch	10 <sub>A</sub>	10 <sub>B</sub>	10 <sub>C</sub>	10 <sub>D</sub>	10 <sub>E</sub>	10 <sub>F</sub>	10 <sub>G</sub>	10 <sub>H</sub>	10 <sub>I</sub>
Initial State	N	N	N	N	I	I	I	I	I
After site failure	WA	N	N	WB	I	I	I	I	I
After T <sub>WAIT</sub> delays	SA	N	N	SB	I	I	I	I	I
Flow reach 10 <sub>E</sub> and 10 <sub>I</sub>	SA	N	N	SB	HA	I	I	I	HB
Flow reach 10 <sub>F</sub> and 10 <sub>H</sub>	SA	N	N	SB	HA	HA	I	HB	HB
Flow reaches 10 <sub>G</sub>	SA	N	N	SB	HA	HA	HA	HB	HB
Flow from 10 <sub>H</sub> reaches 10 <sub>G</sub>	SA	N	N	SB	HA	HA	LA	HB	HB
Flow from 10 <sub>G</sub> reaches 10 <sub>H</sub>	SA	N	N	SB	HA	HA	LA	LB	HB
Flow from 10 <sub>H</sub> reaches 10 <sub>F</sub>	SA	N	N	SB	HA	N	LA	LB	HB
Flow from 10 <sub>H</sub> reaches 10 <sub>E</sub>	SA	N	N	SB	N	N	LA	LB	HB
Flow from 10 <sub>H</sub> reaches 10 <sub>A</sub>	LA	N	N	SB	N	N	LA	LB	HB
Flow from 10 <sub>G</sub> reaches 10 <sub>I</sub>	LA	N	N	SB	N	N	LA	LB	N
Flow from 10 <sub>G</sub> reaches 10 <sub>D</sub>	LA	N	N	LB	N	N	LA	LB	N
Final state	LA	N	N	LB	N	N	LA	LB	N

**Table 3: Summary of Significant State Transitions in Response to Site Failure.**

5

Note 1: The sequence of transitions shown above is only one of many valid possible sequences.

Note 2: No time scale is implied by Table 3.

10 Site 90 is arranged in such a manner that a power failure at switch 10<sub>B</sub> or 10<sub>C</sub> or the node causes the power supply to all switches at site 90 to be switched OFF.

Note that the topology shown above is suitable to protect against the failure of a site, the failure of one or more links to the site, or combinations of failures of links and the site.

15 Switches 10 are able to protect simple point to point link topologies. The time delay T<sub>WAIT</sub> may be set optionally to zero at the innermost two switches which are immediately adjacent to a protected link. Two benefits are provided by setting the time delay T<sub>WAIT</sub> to zero:

- 20 • very high speed protection switching performance of the switches 10 may be achieved; and

- the design and manufacture of switch 10 may be simplified.

Figure 17 shows one topology which would be used to protect a point to point channel  $C_1$  comprising a pair of links 37 between a site 94 and a site 96. Two redundant channels  $C_2$  and  $C_3$  are shown. When channel  $C_1$  represents a subscriber access connection to a public telecommunications network the site 94 would represent the subscriber's premises and the phantom line 39 represents the subscriber interface which would be crossed by the subscriber access links and redundant links. The equipment 98 would represent customer premise equipment (CPE) or other end user equipment. The site 96 would represent the public network. (Alternately when channel  $C_1$  represents a trunk the sites 94 and 96 would represent separate exchange buildings or central offices.) Redundant channel  $C_2$  is connected to the protected links at switches  $10_B$  and  $10_D$ . Redundant channel  $C_3$  connected to the protected links at switches  $10_A$  and  $10_E$ . Further switches  $10_C$  and  $10_F$  are shown which provide additional internal protection to the network.

15

The innermost switches  $10_B$  and  $10_D$  which connect to the first redundant channel  $C_2$  are the first switches to operate after a failure of any link 37 of channel  $C_1$ . It is possible to dispense with the TA and TB timers in this way because the switches are not expected to receive any transmission "gaps" from the failed link channel. The state machines described above still apply, however switches  $10_B$  and  $10_D$  would pass through the WAIT A and WAIT B states instantaneously after detecting any loss of flow on channel  $C_1$ . In effect those switches would make a state transition directly from the NORMAL state to a LOCK or SKEW state. The setting of  $T_{WAIT}$  to zero is optional:  $T_{WAIT}$  may be zero; and  $T_{WAIT}$  may be non-zero. Both options are available in embodiment of the invention.

25

The following provides a detailed description of the delays which are encountered during protection switching. The failure of a link causes a transmission "gap" to be propagated downstream along the link from the point of failure. Gaps with a duration of less than a time  $T_{WAIT}$  do not activate protection switching in the switches 10. Only a first downstream switch 10 performs protection switching in response to that loss of flow, and only after a time greater than  $T_{WAIT}$ . Where  $T_{WAIT}$  is zero protection switching occurs immediately after the loss of flow condition has been detected. Therefore, when a switch

30



10 in the NORMAL state detects the loss of flow on either inputs 12 or 16:

1. the switch 10 switches from the NORMAL state into either the WAIT A state or the WAIT B state and as soon as possible thereafter commences transmitting the dummy flow downstream on the failed link so that the duration of the transmission gap sensed downstream is minimised;
  2. if the delay time  $T_{\text{WAIT}}$  is greater than zero, the switch 10 waits one delay time  $T_{\text{WAIT}}$  to allow any transmission gaps to pass by before switching to one of the LOCK A, LOCK B, SKEW A or SKEW B states;
  - 3a. if any flow is detected again (ie. the flow has been restored for some reason or a dummy flow is detected) the switch 10 reverts immediately to the NORMAL state;
  - 3b. if the flow is still absent at the end of the time  $T_{\text{WAIT}}$ , the switch 10 switches to one of the LOCK A, LOCK B, SKEW A or SKEW B states.
- 15 The delay  $T_{\text{WAIT}}$  is calculated from the time of the most recent loss of flow. When the flow is intermittent the  $T_{\text{WAIT}}$  timer is restarted at each instant that the loss of flow is newly detected. When the detected transmission gaps are shorter than  $T_{\text{WAIT}}$  the switch 10 returns to the NORMAL state at the end of each gap. Only when the flow has been lost for a continuous period greater than  $T_{\text{WAIT}}$  the switch 10 switches to a SKEW or LOCK state.
- 20 The delay  $T_{\text{WAIT}}$  ensures that any switch 10 which may exist downstream from the point of failure does not disrupt unnecessarily the contra-flowing flow. Only the switch 10 adjacent to and immediately downstream from a point of failure switches into the LOCK A, LOCK B, SKEW A or SKEW B state.

	Comment	Switch 10 <sub>A</sub>	Switch 10 <sub>B</sub>	Flow Received at Site 102	Time Values
	Immediately prior to failure	N	N	flow from 100	
5	After detection of failure at 10 <sub>B</sub>	N	WB	X	↑ ↑
	During switching at 10 <sub>B</sub>	N	WB	X	T <sub>SWITCH</sub>
	During switching at 10 <sub>B</sub>	N	WB	X	↓ T <sub>WAIT</sub>
	After switching completed at 10 <sub>B</sub>	N	WB	dummy flow from 10 <sub>B</sub>	
	During WAIT B state at 10 <sub>B</sub>	N	WB	dummy flow from 10 <sub>B</sub>	↓
10	After Expiry of T <sub>WAIT</sub> at 10 <sub>B</sub>	N	SB	dummy flow from 10 <sub>B</sub>	↑
	During propagation delay 43	N	SB	dummy flow from 10 <sub>B</sub>	propagation delay 43
	During propagation delay 43	N	SB	dummy flow from 10 <sub>B</sub>	↓
	After detection of failure at 10 <sub>A</sub>	WA	SB	dummy flow from 10 <sub>B</sub>	↑
	During and after switching at 10 <sub>A</sub>	WA	SB	dummy flow from 10 <sub>B</sub>	T <sub>WAIT</sub>
	During WAIT A state at 10 <sub>A</sub>	WA	SB	dummy flow from 10 <sub>B</sub>	↓
15	After detection of flow at 20 (10 <sub>A</sub> )	LA	SB	dummy flow from 10 <sub>B</sub>	↑
	During propagation delay 51	LA	SB	dummy flow from 10 <sub>B</sub>	propagation delay 51
	During propagation delay 51	LA	SB	dummy flow from 10 <sub>B</sub>	↓
	After propagation delay 51	LA	LB	X	↑
	During switching at 10 <sub>B</sub>	LA	LB	X	T <sub>SWITCH</sub>
20	During switching at 10 <sub>B</sub>	LA	LB	X	↓
	After switching at 10 <sub>B</sub>	LA	LB	flow from 100	
	Steady state	LA	LB	flow from 100	

**Table 4: Timing Relationships**

Note: No time scale is implied by Table 4.

25

Figure 18 shows two sites 100 and 102 connected by a network and switches 10<sub>A</sub> and 10<sub>B</sub>. Table 4 illustrates the delays which occur after the failure of link 41 and the relationship with state transitions at switches 10<sub>A</sub> and 10<sub>B</sub>. Time in the table passes from the top downwards. "X" represents an indeterminate transitional value which may occur during switching in real devices. Initially both switches 10<sub>A</sub> and 10<sub>B</sub> are in the NORMAL state and site 100 transmits to site 102 via the link 41. The network is arranged so that the

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transmission delay between switch 10<sub>B</sub> and the receiving site 102 is negligible.

Link 41 fails at location 53. The loss of flow is detected at input 12 of switch 10<sub>B</sub>. Switch 10<sub>B</sub> takes a finite switching time  $T_{\text{SWITCH}}$  before it is able to activate and to transmit its dummy flow in state WAIT B towards site 102. If no incoming flow from switch 10<sub>A</sub> via link 41 is detected at switch 10<sub>B</sub> at the end of time  $T_{\text{WAIT}}$ , switch 10<sub>B</sub> switches to the SKEW B state. After the propagation delay incurred in traversing link 43 the flow at input 16 of switch 10<sub>A</sub> is lost. Switch 10<sub>A</sub> switches from the NORMAL state to the WAIT A state. Let switch 10<sub>A</sub> detect at its input 20 the incoming flow from switch 10<sub>B</sub> while still in the WAIT A state. Switch 10<sub>A</sub> switches to the LOCK A state after the delay  $T_{\text{WAIT}}$ . The flow on link 49 presented to input 12 of switch 10<sub>A</sub> is then transmitted to switch 10<sub>B</sub> via the protection link 51. When detected at input 20 of switch 10<sub>B</sub> after the propagation delay incurred in traversing link 51, switch 10<sub>B</sub> switches from the SKEW B state to the LOCK B state, completing the repair action. The required flow from site 100 is again received at site 102.

Figure 19 illustrates the relationship between the time delays. At the top is shown a digital link flow whose value alternates between a high value 1 and a low value 0 as time passes to the right. The illustration is not to scale. The illustration may represent a digital optical flow which turns ON and OFF, or an electrical flow which alternates between a high voltage and a low voltage. The time 104 is the longest expected zero sequence in a normal flow. To successfully detect the loss of flow condition the switch 10 must fail to detect a flow for at least the time  $T_{\text{DETECT}}$  106, which consists of the longest expected zero sequence 104 together with an error tolerance 108. The longest expected zero sequence 104 is the longest expected period for which received flow may be absent from a healthy flow including a dummy flow. Transmission gaps with a duration of less than a time  $T_{\text{DETECT}}$  106 are not interpreted as "linked failed". The absence of a flow for greater than  $T_{\text{DETECT}}$  106 is interpreted as "link failed". Therefore  $T_{\text{DETECT}}$  is dependent upon the transmission bit rate and the line coding scheme used. For example, in a digital optical embodiment in which logical "zeros" are represented by the absence of light,  $T_{\text{DETECT}}$  would be greater than the duration of the greatest expected number of consecutive optical "zeros" divided by the line rate measured in bits per unit time at the lowest transmission bit rate for which

the module is designed.

The figure shows a healthy flow. If on the other hand the flow remained at zero for at least the time  $T_{\text{DETECT}}$  106 then the flow would be deemed lost and one or more switch 10 state changes would be initiated. At the instant marked 110 at the end of  $T_{\text{DETECT}}$  106 if the flow is still absent (not shown in the figure) a switch 10 switches from the NORMAL state to a WAIT state.

Any realisation of the switch 10 requires a finite time to perform switching operations and to activate and transmit the dummy flow if necessary.  $T_{\text{SWITCH}}$  112 is the maximum time required to implement any changes of state at any switch 10 in a network.  $T_{\text{SWITCH}}$  112 is equal to or greater than the time required to activate, switch and transmit the dummy flow and to perform all other switching functions. The longest possible transmission gap which is propagated downstream is less than or equal to the sum of  $T_{\text{DETECT}}$  106 and  $T_{\text{SWITCH}}$  112. Downstream switches 10 remain in a WAIT state for at least a time  $T_{\text{WAIT}}$  in order to allow any transmission gaps from upstream to flow by. In any realisation of a switch 10 with  $T_{\text{WAIT}}$  not equal to zero,  $T_{\text{WAIT}}$  114 is therefore required to be equal to or greater than the sum of: i) the switching time  $T_{\text{SWITCH}}$  112; ii)  $T_{\text{DETECT}}$  106; and iii) the further delay 116, which provides a sufficiently large margin so that  $T_{\text{WAIT}}$  at any switch 10 in the network is always greater than the longest possible transmission gap.

For example: if the longest expected zero sequence 104 on a 10Km, 155.52 Mbps optical point to point link is four optical zeros then  $T_{\text{DETECT}}$  106 would be greater than the time 104 and would be given by:

25

$$T_{\text{DETECT}} > 4 / (155.52 \times 10^6) \text{ seconds} = 25.7 \text{ nanoseconds}$$

With a 74 nanosecond error tolerance 108 the decision to switch to the WAIT A or WAIT B state from the NORMAL state may be made within 100 nanoseconds of the detection of loss of flow. With an additional maximum switching time  $T_{\text{SWITCH}}$  112 also of 100 nanoseconds the maximum duration of any transmission gap would be

30

200 nanoseconds. Setting the TA and TB timer delays  $T_{WAIT}$  114 to 500 nanoseconds each provides a 300 nanosecond margin 116. Switching to a SKEW or LOCK state would occur within 500 nanoseconds of the detection of loss of flow at each switch. If the flow travelled at  $2 \times 10^8$  m/sec then the round trip flow propagation delay would be

5

$$2 \times 10^4 / 2 \times 10^8 \text{ seconds} = 100 \mu\text{seconds}$$

Therefore in the worst case which occurs when one link fails near a transmitter protection switching would be completed within 101  $\mu$ seconds. In the best case which occurs when  
10 each link fails near a receiver protection switching would occur within 500 nanoseconds. In the best case the protected flow in one direction would be switched to and transmitted along the redundant link almost immediately after the link failure. The receiving site downstream would receive the flow from the redundant link/channel almost immediately after detecting the loss of flow (assuming that the transmission delays of the protected  
15 link and the redundant link were comparable). By making the redundant link shorter than the protected link, the receiver would receive the diverted flow from the redundant link before the receiver lost the flow from the normal link. Setting the TA and TB timer delays  $T_{WAIT}$  to zero furnishes very high speed protection switching. For the example above, protection switching would be completed in less than 200 nanoseconds at each switch 10.  
20 Better performance would be achieved by reducing the generous margins given in this example. When the propagation delay in the protected link is identical to the propagation delay in the redundant link it is possible to switch paths without losing bit or frame synchronisation at the receiving sites.

25 After the failed links and sites have been repaired flows would be restored to the links which were originally used. Restoration of flows is achieved by forcing one or more switches 10 into the NORMAL state. A forced state transition at one switch 10 may automatically initiate state transitions at other remote switches 10. The forced switch 10 together with other switches 10 co-operatively achieve restoration. It is not necessary to  
30 force state transitions at all switches 10. For example the restoration of a flow to one of the pair of links 37 from one of the redundant links of channel  $C_2$  in Figure 17 after the

failure and subsequent repair of channel  $C_1$  would be achieved by forcing only one local switch  $10_D$  at for example the exchange end into the NORMAL state. The loss of flow from the redundant links and the detection again of a flow on the normal link at the remote switch  $10_B$  together are sufficient to cause switch  $10_B$  also to switch to the NORMAL state, so completing restoration.

Switches 10 and switching systems in accordance with this invention can thus be controlled from remote locations. This feature is of benefit to network operators who would be spared the expenses of additional network management networks, and travelling of technicians to switches 10 at remote sites.

Networks would be protected against the failure of switches 10 either: by installing switches together with separate active or passive by-pass devices; or by incorporating a passive by-pass device into switches. Figure 20 shows a separate by-pass device 118. Operation of the by-pass device would be controlled either: directly by the switch  $10_A$  via a control line 120 as shown; or by some other device. Failure of the switch  $10_A$  or its power supply would cause the by-pass device 118 to be switched so that the bidirectional through paths 122 and 124 are enabled and so that the failed switch  $10_A$  is by-passed. When in the by-passed state any flow or flows received at input 126 are transferred to output 128 and any flows received at input 130 are transferred to output 132. When not in the by-passed state the flows at inputs 126 and 130 are transferred to the switch  $10_A$ . The failure of any power supply which may be required by the by-pass device 118 would also cause the switch  $10_A$  to be by-passed.

Now that embodiments of this invention have been described in detail it will be apparent to those skilled in the relevant arts that numerous modifications and variations may be made without departing from the basic inventive concepts. For example, embodiments of the invention may be realised using a microprocessor to control the switches 10 instead of a field programmable gate array. Indeed, embodiments of the invention may be realised entirely in software that may be hosted in a computer, communications equipment or other equipment that may be installed at sites in a network. The software would implement the invention by altering routing tables, configuration tables or other mapping tables which

specify associations between incoming and outgoing links and any of packet source addresses; packet destination addresses; telephone numbers; sockets; ports; incoming links; outgoing links; node addresses; connections; virtual channels; virtual paths; SDH tributary units (TU-ns); SONET virtual tributaries (VT-ns); user group multiplex labels; channel identifiers; routes; and other types of channels. Channels, paths, connections and routes would thus be remapped to links that connect to healthy parts of the network in response to the detection of a loss of flow condition. The loss of flow condition may be detected either by software or by signals from line interfaces and other devices within the host.

10

It is also important to note that embodiments of the invention may be structured in a manner so that say  $P_1$  and  $P_3$  would support links with different characteristics from the links at the other port  $P_2$ . For example one embodiment of the switch 10 for telecommunications networks would include high power interfaces at  $P_1$  and  $P_3$  that support long range flows, while the remaining port  $P_2$  will include a low power interface for short range flows. This arrangement would enable the switch 10 to be installed in an exchange building or central office between existing transmission equipment and the transmission line. The low power port  $P_2$  would connect to nearby equipment over shorter range links. The high powered ports  $P_1$ ,  $P_3$  will connect to the longer range protected and protection lengths. Further, in embodiments of the switch 10 line interfaces can be used at the ports in which the bandwidth transmitted onto one or more outgoing links is not equal to the band width received from an incoming link. Switches 10 may thus be constructed for installation in networks that support asymmetric digital subscribed lines (ADSLs).

Also, while embodiments of the invention have been described incorporating a dummy flow generator such a generator is not essential for the protection of point to point links and other network topologies.

Where a synchronising timing structure is embedded within a flow, embodiments of the invention may include a time extraction mechanism that recovers synchronising timing from the flow. The timings though recovered may be employed to synchronise the transmission of one or more outgoing flows from a switch. The use of timing recovery

and flow generation would enable the maximum number of switches 10 that may be concatenated along a set of links to be greater than embodiments that do not perform regeneration. A wide range of timing recovery components is available both as discrete components or integrated into receiver components.

5

Embodiments of the switch may include a device or system that monitors and optionally performs switching as a result of fault status or alarm signals furnished by and received from other sites in the network. For example, a switch 10 may be constructed that performs switching functions in response to the receipt of fault status, alarm or other  
10 signals.

Embodiments of the switch 10 can also be arranged or operated to detect the restoration of a normally used link after having failed, and automatically re-route a flow back onto that normal link. The requirement for manual intervention to divert a flow from a protection  
15 link to a protected link would thus be eliminated. The detection of link restoration may be achieved by transmitting a signal onto a failed link which would be received after restoration of that link.

One range of embodiments of the switch 10 may be constructed to protect the flow of the  
20 electrical energy through transmission and distribution networks that span or are contained within one or more continents or nations, a smaller region, a vehicle or machine, a circuit board, and a silicon or other microchip. Each switch 10 would generate a flow of electrical protection signals and transmit onto the electrical power transmission conductors, in both directions. Each physical link in the transmission network would  
25 facilitate both a flow of electrical energy in either or both directions; and, a flow of protection signals in either or both directions. The switches 10 would divert the protected power flow onto healthy links in response to loss of receipt of protection signals.

Finally, as mentioned above, the switches 10 can be constructed to protect networks other  
30 than electrical/electro-magnetic communication systems for example to protect networks of vacuum tubes that transport pneumatically propelled canisters; to protect blood vessels and other carriageways in human and other bodies to retain full connectivity between say



the heart or other pump and other parts of the body. In this embodiment, the detection means would detect characteristics of blood flow such as blood pressure. Loss of blood pressure along one blood vessel would activate bypass switching to a standby redundant path/blood vessel. A completely distributed network of blood carrying tubes or conduits  
5 connected via switches 10 could be constructed to create an extremely robust being.

All such modifications and variations together with others that would be obvious to a person of ordinary skill in the art are deemed to be within the scope of the present invention the nature of which is to be determined from the above description and the  
10 appended claims.

The claims defining the invention are as follows:

1. A switch comprising at least:

first, second and third ports ( $P_1$ - $P_3$ ) each having an input and an output;

5 the switch arranged so that a first flow presented to the input of one of  $P_1$ - $P_3$  is delivered to the output of an other of  $P_1$ - $P_3$ , and a second flow presented to the input of said other of  $P_1$ - $P_3$  is delivered to the output of said one of said  $P_1$ - $P_3$ ;

detection means for detecting a predetermined characteristic of the flows presented at the input of each of  $P_1$ - $P_3$ ; and,

10 control means which, upon the detecting means detecting said predetermined characteristics in one of said first flow and said second flow, internally diverts the other of the first flow and second flow to be presented to the output of a remaining one of  $P_1$ - $P_3$ .

15 2. The switch according to claim 1 further including timer means for counting a time T for which the detecting means detects the existence of said predetermined characteristic of the flows and wherein said control means only diverts the other of the first and second flows to the output of said remaining one of  $P_1$ - $P_3$  when the time T is equal to or exceeds a predetermined time  $T_{wait}$ .

20

3. The switch according to claim 2 further including a dummy flow means for producing a dummy flow and, said control means delivers said dummy flow to the output of the port to which said one of said first and second flows would be delivered in the absence of that flow being detected as having said predetermined characteristic.

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4. The switch according to claim 2 or 3 wherein, said predetermined characteristic is the absence of said flow for said period  $T_{wait}$ .

5. The switch according to claims 2 – 4 wherein said period  $T_{wait}$  is 0.

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6. The switch according to any one of claims 2-5 wherein said period  $T_{wait}$  is different for each of  $P_1$ - $P_3$ .

7. The switch according to any one of claims 1 to 6 wherein said predetermined characteristic is a predetermined reduction in the rate of flow at said inputs.
- 5 8. The switch according to any one of claims 1 to 6 wherein when said flows relate to communication signals, said predetermined characteristic is a predetermined bit error rate, or signal to noise ratio.
9. The switch according to any one of claims 3 to 8 wherein said dummy flow means is  
10 in the form of a generator for generating a flow of the same type as the flow presented to the inputs of said switch.
10. The switch according to any one of claims 3 to 8 wherein said dummy flow means  
15 includes means for sampling and subsequently replicating the flow presented to the inputs of the switch.
11. The switch according to any one of claims 1 to 10 wherein said detection means is  
further able to detect the absence of said predetermined characteristic after said control  
means has internally diverted said other of the first flow and second flow to the output  
20 of the remaining one of  $P_1$ - $P_3$ , whereup said control means rediverts said other of the  
first flow and second flow to be presented to the output of the other or one of  $P_1$ - $P_3$ , as  
the case may be.
12. The switch according to any one of claims 1 to 11 further including a fourth port  $P_4$   
25 having an input and an output in communication with said control means for  
allowing external control of said control means including to control said control  
means to force a change in state of said switch.
13. The switch according to any one of claims 1 to 12 further including signal  
30 generating means for generating a status signal containing information relating to  
the status of said switch including any faults detected by said detecting means and  
wherein said status signal is delivered to an output of one of said ports  $P_1$ - $P_4$ .

14. The switch according to claim 13 wherein said control means is configured to act as said signal generating means.

5 15. The switch according to claims 13 or 14 wherein said control means is configured to add or embed said status signal to the flow delivered to the output of said other or said remaining one of said ports  $P_1$ - $P_3$ , or the output of port  $P_4$ .

10 16. A distributed network protection switching system for a network having at least first and second sites ( $X_1$ ,  $X_2$ ) a first channel  $C_1$  to allow bidirectional transfer of flows between said sites; and at least one further channel  $C_2$  to provide an alternate route for bidirectional transfer of flows between said sites, each channel having a unidirectional incoming link and an unidirectional outgoing link; the system including at least:

15 a first switch ( $S_1$ ) and a second switch ( $S_2$ ), each of  $S_1$ , and  $S_2$  being in accordance with any one of claims 1-15,  $S_1$  coupled to the first site ( $X_1$ ) so that a flow out of  $X_1$  is presented to the input of any one of  $P_1$ - $P_3$  of  $S_1$  and a flow into  $X_1$  is delivered from the output of said one of  $P_1$ - $P_3$  of  $S_1$ ;

20  $S_2$  coupled to  $X_2$  so that a flow out of  $X_2$  is presented to the input of any one of  $P_1$ - $P_3$  of  $S_2$  and a flow into  $X_2$  is delivered from the output of said one of  $P_1$ - $P_3$  of  $S_2$ ;

an outgoing link of channel  $C_1$ , viewed from  $X_1$ , connected between the output of an other of  $P_1$ - $P_3$  of switch  $S_1$  and the input of an other of  $P_1$ - $P_3$  of switch  $S_2$ ;

an incoming link of channel  $C_1$ , viewed from site  $X_1$ , connected between the input of said other of  $P_1$ - $P_3$  of switch  $S_1$  and the output of said other of  $P_1$ - $P_3$  of switch  $S_2$ ;

25 an outgoing link of channel  $C_2$ , viewed from site  $X_1$ , connected between the output of the remaining one of  $P_1$ - $P_3$  of switch  $S_1$  and the input of the remaining one of  $P_1$ - $P_3$  of switch  $S_2$  and, an incoming link of channel  $C_2$  viewed from site  $X_1$  being connected between the input of the remaining one of ports  $P_1$ - $P_3$  of switch  $S_1$  and the output of the remaining one of  $P_1$ - $P_3$  of switch  $S_2$ ;

30 whereby, in use, upon said detection means of one of  $S_1$  and  $S_2$  detecting a predetermined characteristic of a flow presented at its input from channel  $C_1$  internally diverts the flow directed to the output of the port containing that input to the output of

the remaining port thereby causing the detection means of the other one of  $S_1$  and  $S_2$  to detect the absence of a flow at the input of the other one of switches  $S_1$  and  $S_2$  from channel  $C_1$  so that the flow delivered to the output of the other port of switch  $S_2$  is diverted to the output of the remaining port of switch  $S_2$  thereby switching the channel of communication between the first and second sites  $X_1, X_2$  from channel  $C_1$  to channel  $C_2$ .

17. A network with distributed switching protection the network including at least:

first and second sites ( $X_1, X_2$ ) for transmitting and receiving a flow;

a first channel to allow bidirectional transfer of flows between said sites;

at least one further channel to provide an alternate route for bidirectional transfer of flows between said sites, each of said first channel and said at least one further channel having a unidirectional incoming link and a unidirectional outgoing link;

a first switch ( $S_1$ ) and a second switch ( $S_2$ ), each of  $S_1$  and  $S_2$  being in accordance with any one of claims 1-15;

$S_1$  coupled to the first site ( $X_1$ ) so that a flow out of  $X_1$  is presented to the input of any one of  $P_1$ - $P_3$  of  $S_1$  and a flow into  $X_1$  is delivered from the output of said one of  $P_1$ - $P_3$  of  $S_1$ ;

$S_2$  coupled to  $X_2$  so that a flow out of  $X_2$  is presented to the input of any one of  $P_1$ - $P_3$  of  $S_2$  and a flow into  $X_2$  is delivered from the output of said one of  $P_1$ - $P_3$  of  $S_2$ ;

the outgoing link of channel  $C_1$ , viewed from  $X_1$ , connected between the output of an other of  $P_1$ - $P_3$  of switch  $S_1$  and the input of an other of  $P_1$ - $P_3$  of switch  $S_2$ ;

the incoming link of channel  $C_1$ , viewed from site  $X_1$ , connected between the input of said other of  $P_1$ - $P_3$  of switch  $S_1$  and the output of said other of  $P_1$ - $P_3$  of switch  $S_2$ ;

the outgoing link of channel  $C_2$ , viewed from site  $X_1$ , connected between the output of the remaining one of  $P_1$ - $P_3$  of switch  $S_1$  and the input of the remaining one of  $P_1$ - $P_3$  of switch  $S_2$  and, the incoming link of channel  $C_2$  viewed from site  $X_1$  being connected between the input of the remaining one of ports  $P_1$ - $P_3$  of switch  $S_1$  and the output of the remaining one of  $P_1$ - $P_3$  of switch  $S_2$ ;

whereby, in use, upon said detection means of one of  $S_1$  and  $S_2$  detecting a predetermined characteristic of a flow presented at its input from channel  $C_1$ , said one of  $S_1$  and  $S_2$  internally diverts the flow directed to the output of the port containing

that input to the output of the remaining port thereby causing the detection means of the other one of  $S_1$  and  $S_2$  to detect the absence of a flow at the input of the other one of switches  $S_1$  and  $S_2$  from channel  $C_1$  so that the flow delivered to the output of the other port of switch  $S_2$  is diverted to the output of the remaining port of switch  $S_2$ , thereby switching the channel of communication between the first and second sites  $X_1, X_2$  from channel  $C_1$  to channel  $C_2$ .

18. A method of using and operating a switch having first, second and third ports ( $P_1$ - $P_3$ ), each port having an input and an output, said method comprising the steps of :  
coupling an incoming first flow of a first channel to the input of one of  $P_1$ - $P_3$ ;  
internally routing said incoming first flow to the output of an other of  $P_1$ - $P_3$ ;  
coupling an incoming second flow of a second channel to the input of said other of said  $P_1$ - $P_3$ ;  
internally routing said incoming second flow to the output of said one of said  $P_1$ - $P_3$ ;  
monitoring said inputs to detect a predetermined characteristic of the flow at said inputs;  
upon detecting said predetermined characteristic in one of said first flow and said second flow, internally re-routing the other of the first flow and the second flow to the output of a remaining one of the ports  $P_1$ - $P_3$ .

19. The method according to claim 18 further including a step of counting a time  $T$  for which said predetermined characteristic is detected and wherein said step internally of re-routing only occurs if said time  $T$  is equal to or exceeds a predetermined time  $T_{wait}$ .

20. A method according to claim 19 further including a step of generating a dummy flow and internally routing said dummy flow to the output of the port to which said one of said first and second flow would be delivered in the absence of that flow being detected as having said predetermined characteristic.

21. The method according to any one of claims 18-20 wherein said monitoring step includes monitoring said inputs to detect a predetermined reduction in the rate of flows at said inputs.

22. The method according to any one of claims 18-20 wherein, when said flows are in relation to communication signals, said monitoring step includes monitoring said inputs to detect a predetermined bit error rate, or signal to noise ratio.

23. The method according to any one of claims 18-20 wherein said monitoring step includes monitoring said inputs to detect an absence of the flow at said inputs.

24. A method according to claim 20 wherein said step of generating a dummy flow includes the steps of taking one or more samples of said flow presented at the inputs of said switch and constructing said dummy flow from said one or more samples as a replica of the flow presented to the inputs of said switch.

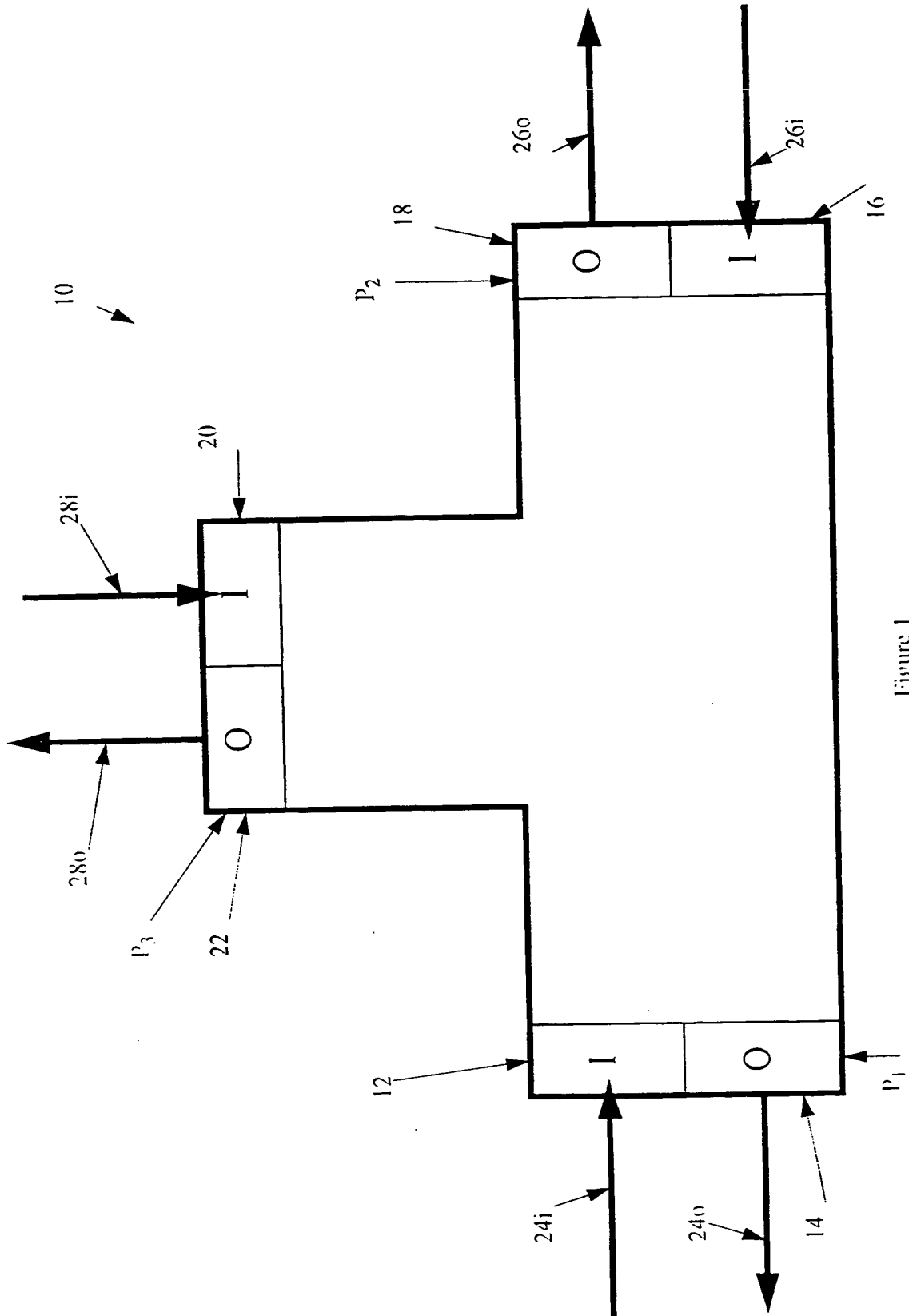


Figure 1



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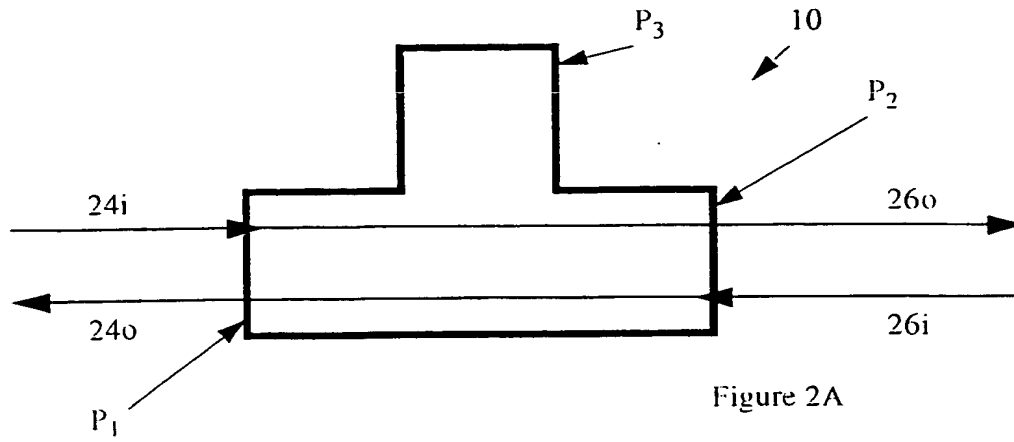


Figure 2A

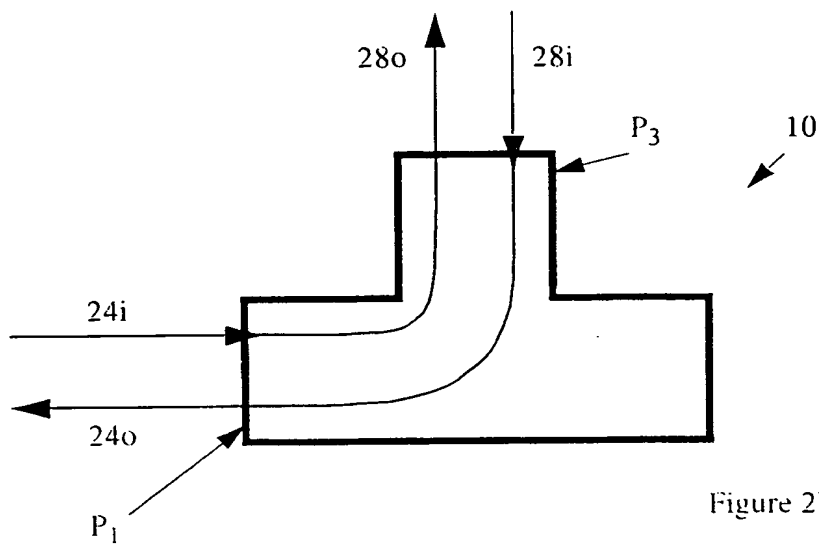


Figure 2B

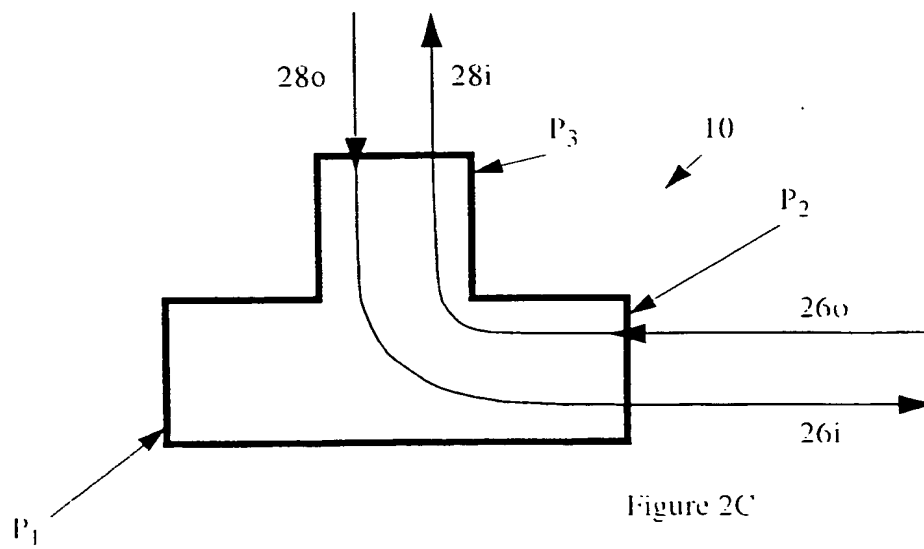


Figure 2C

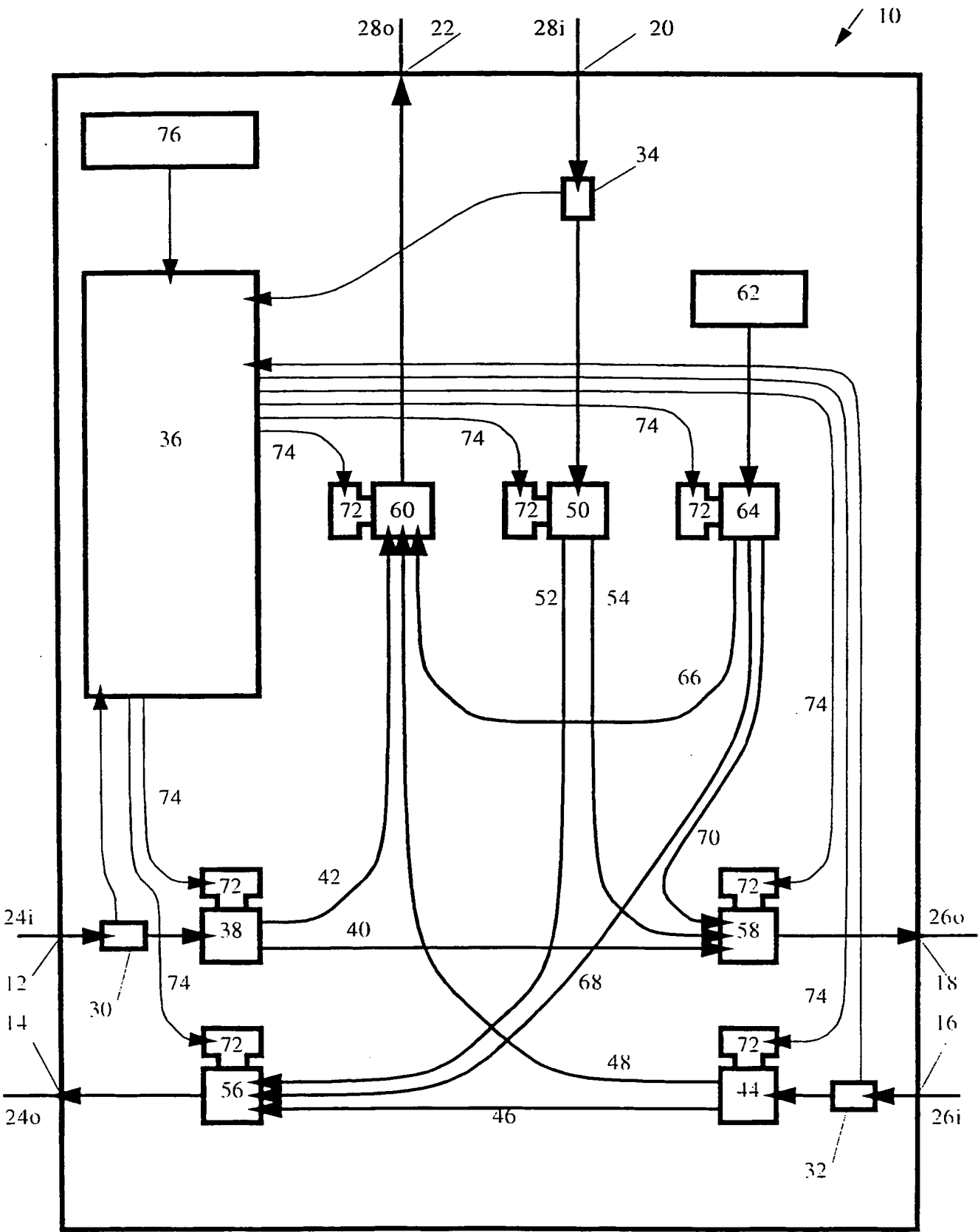


Figure 3

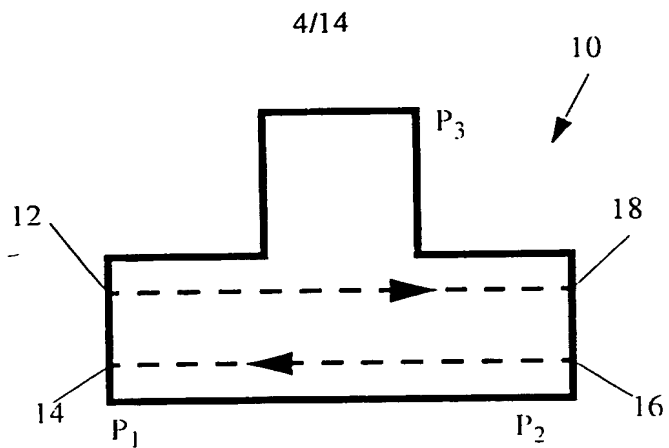


Figure 4

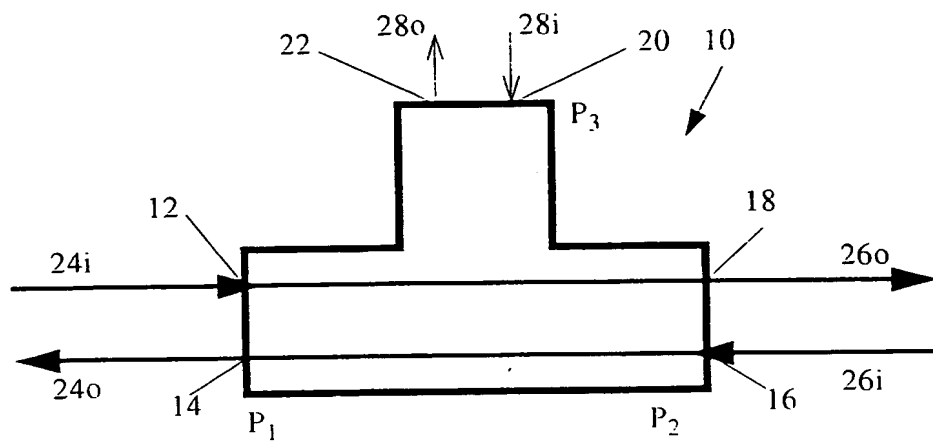


Figure 5

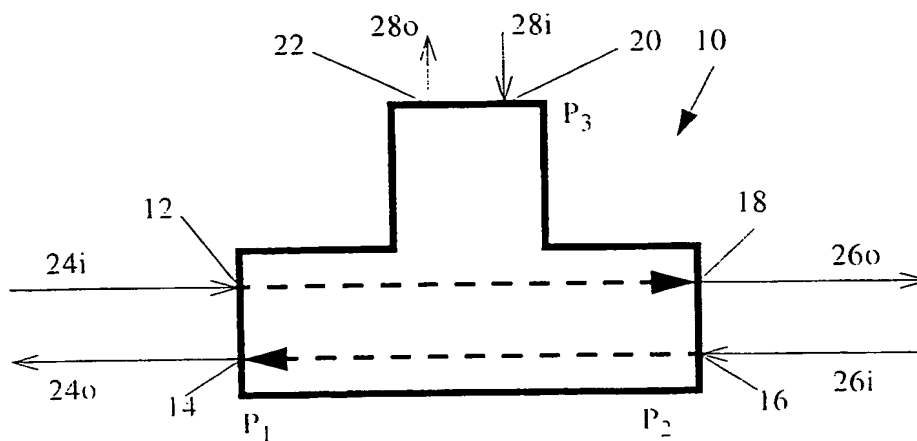


Figure 6

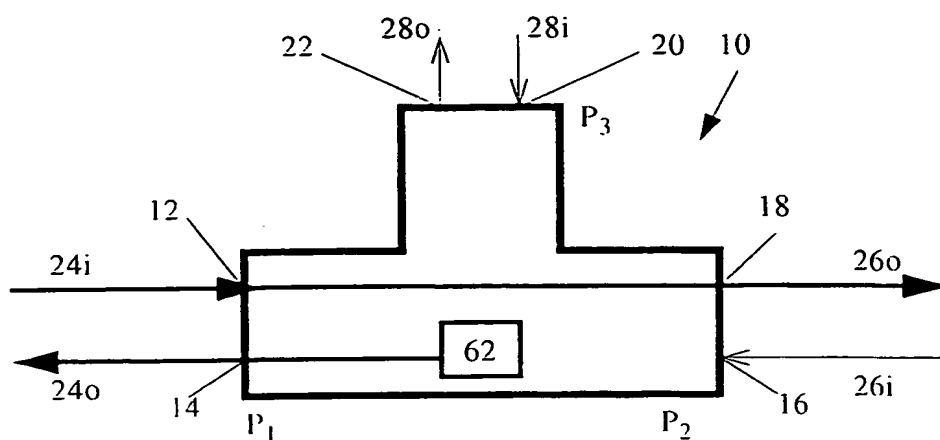


Figure 7

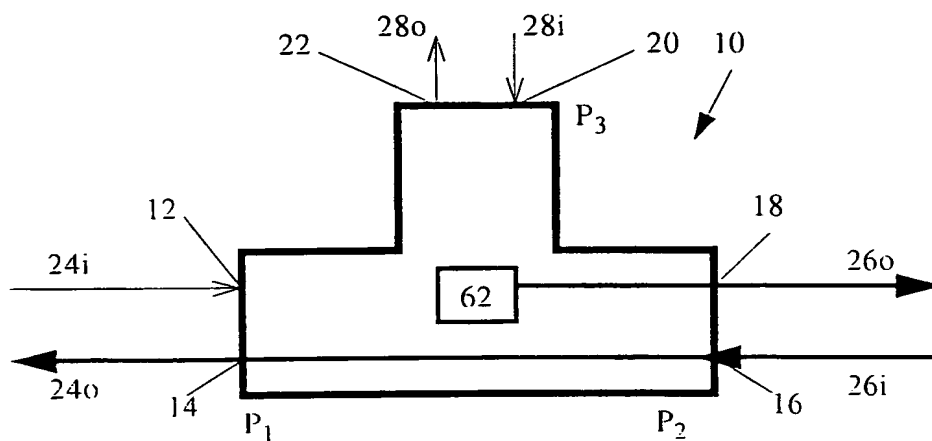


Figure 8

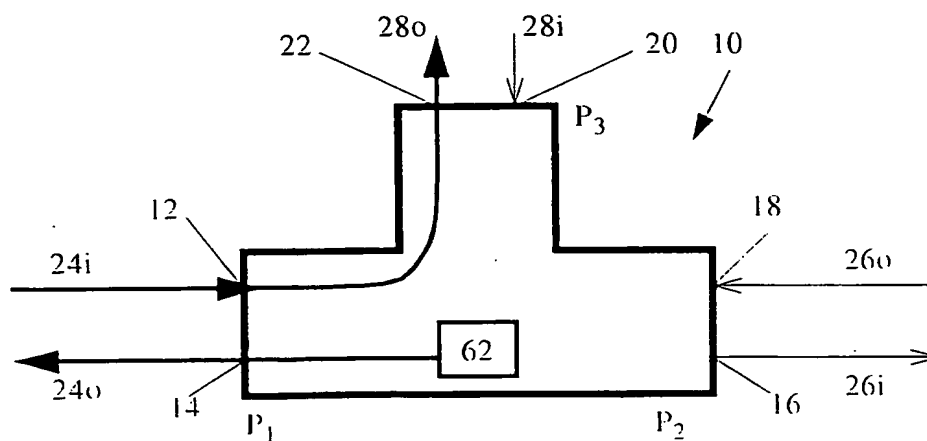


Figure 9

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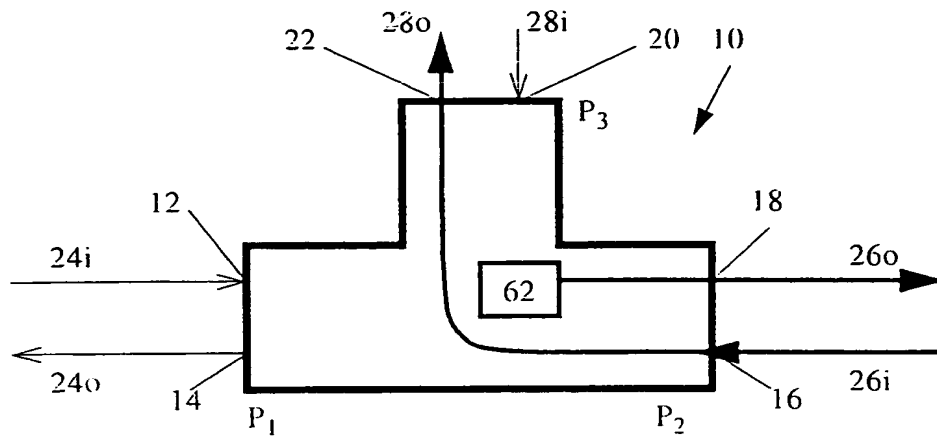


Figure 10

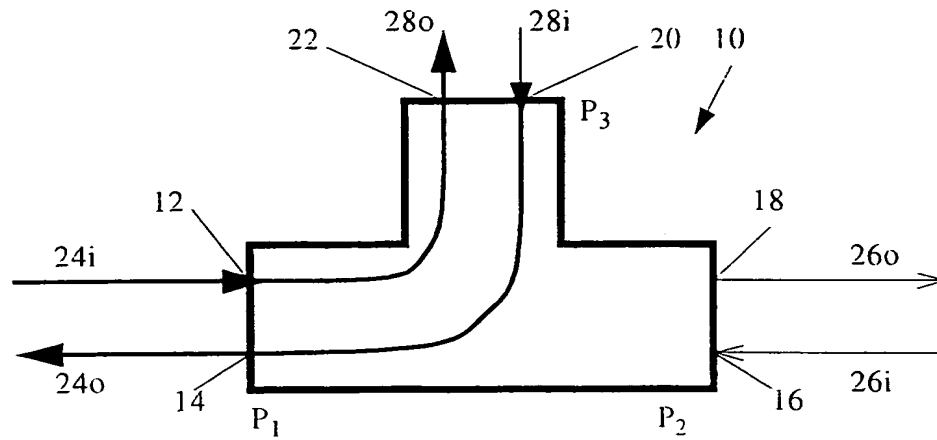


Figure 11

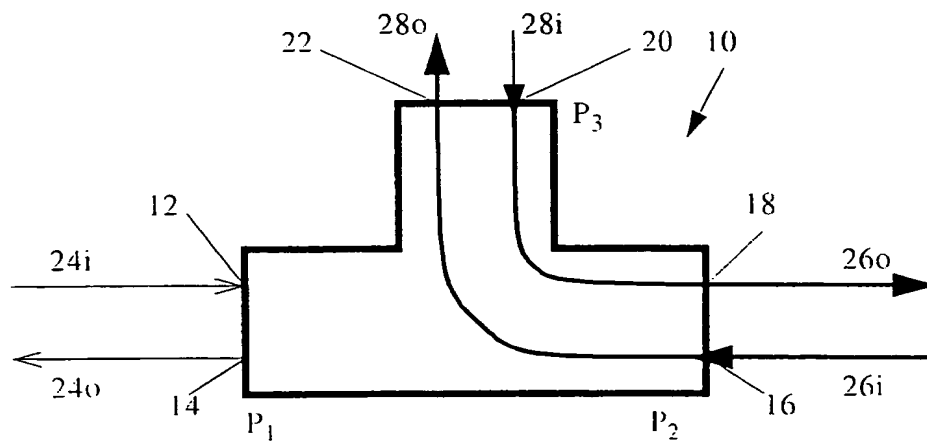


Figure 12

7/14

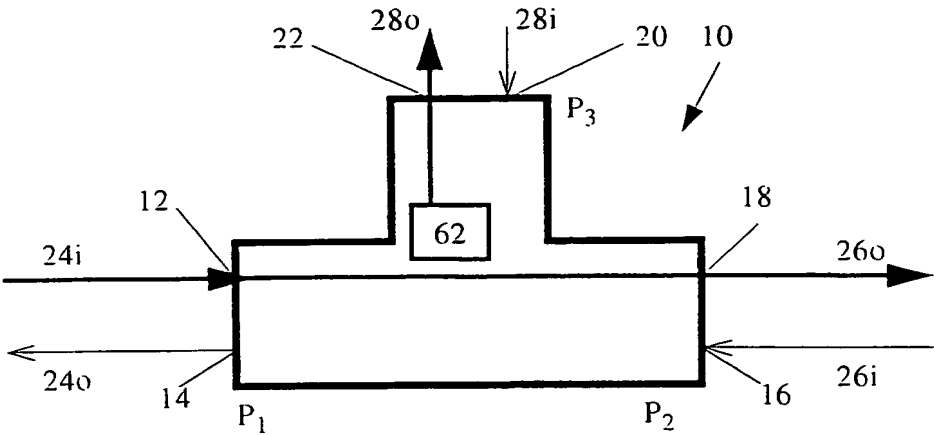


Figure 13

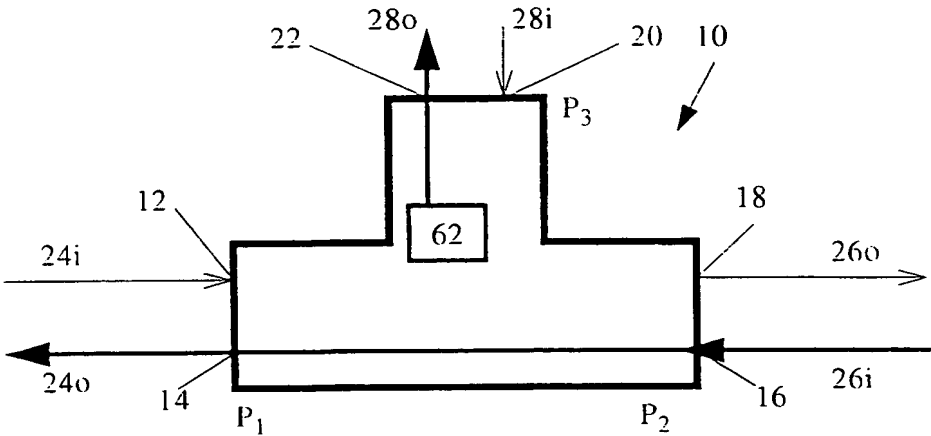


Figure 14

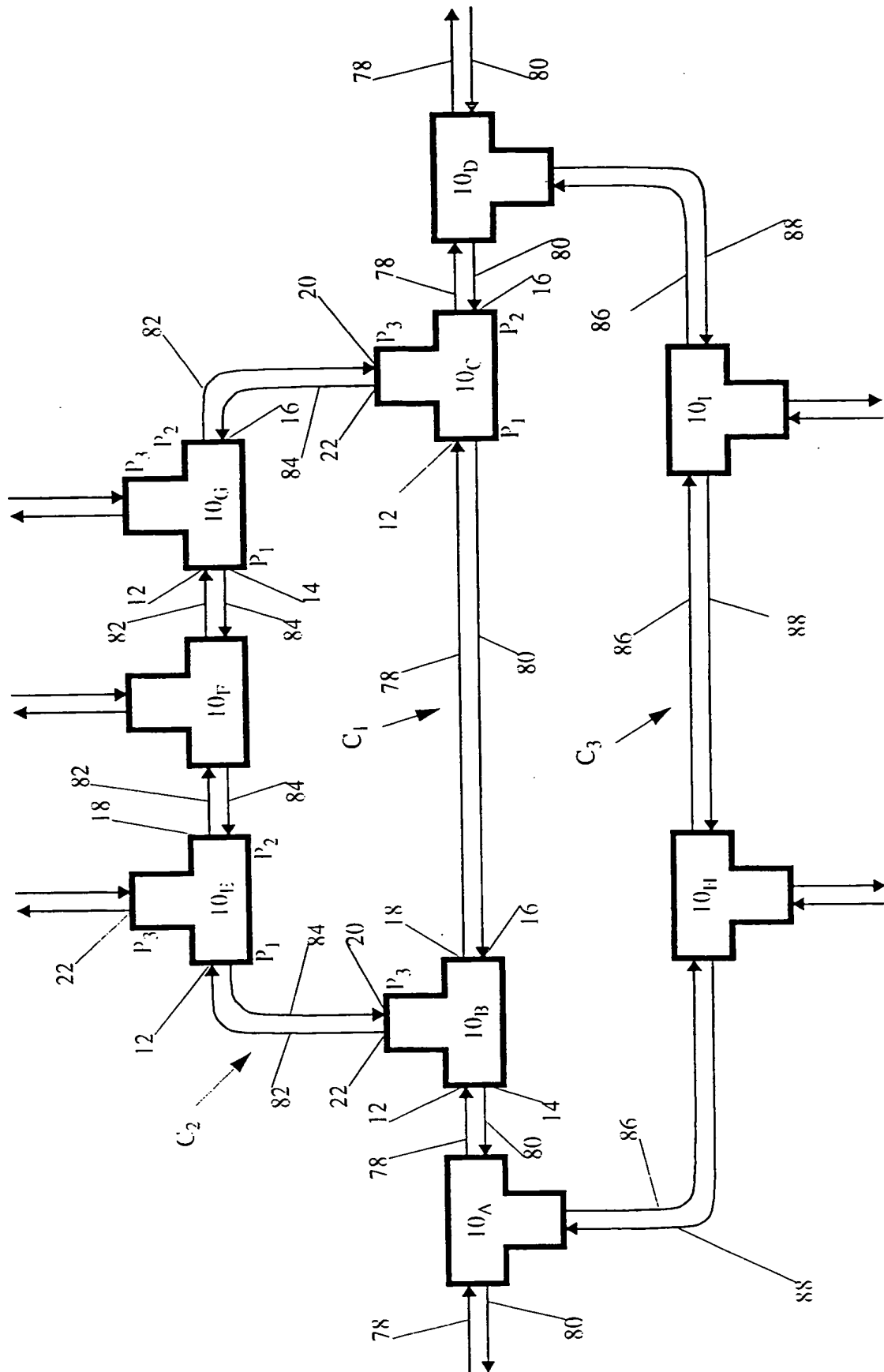


Figure 15

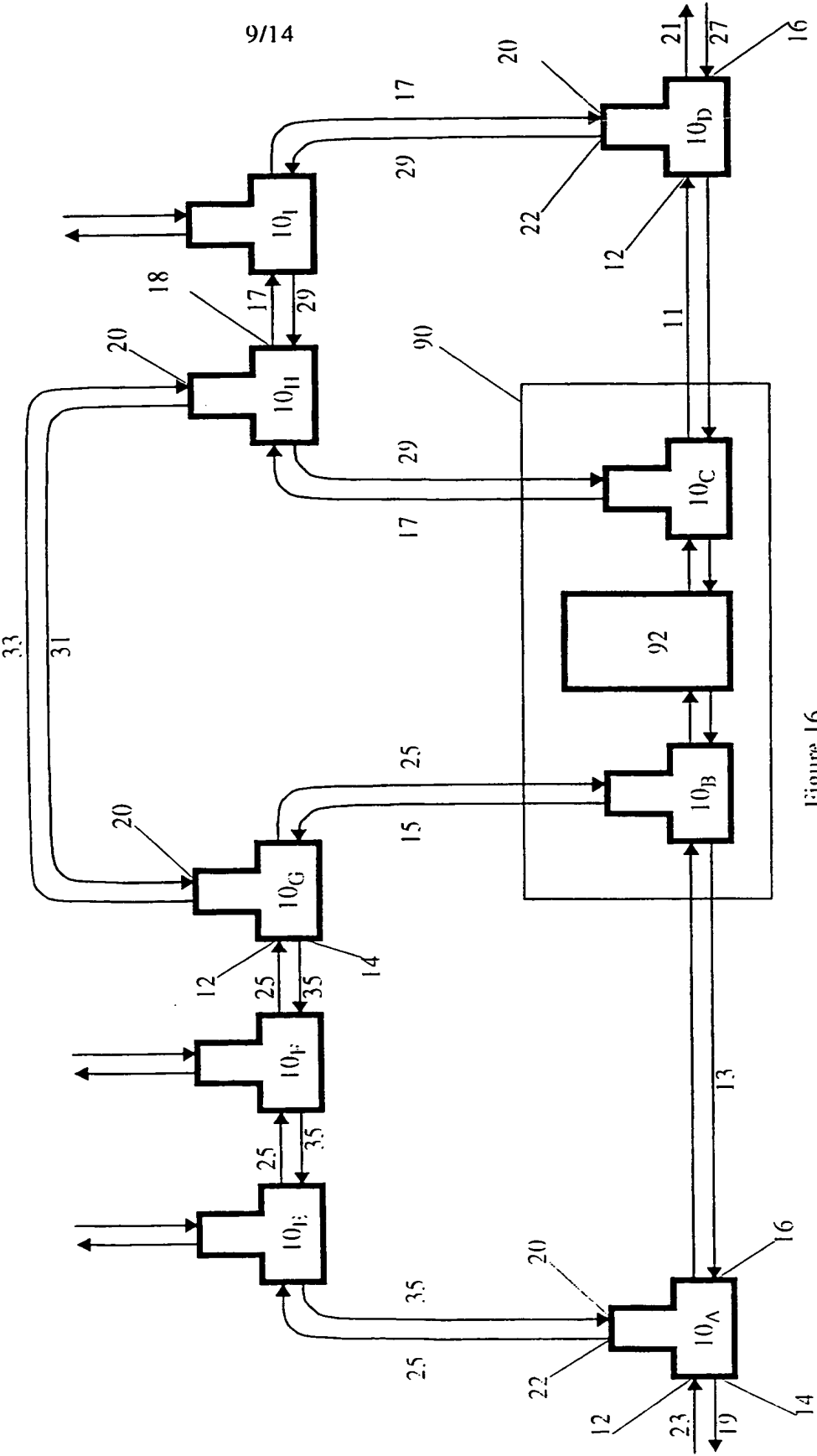


Figure 16



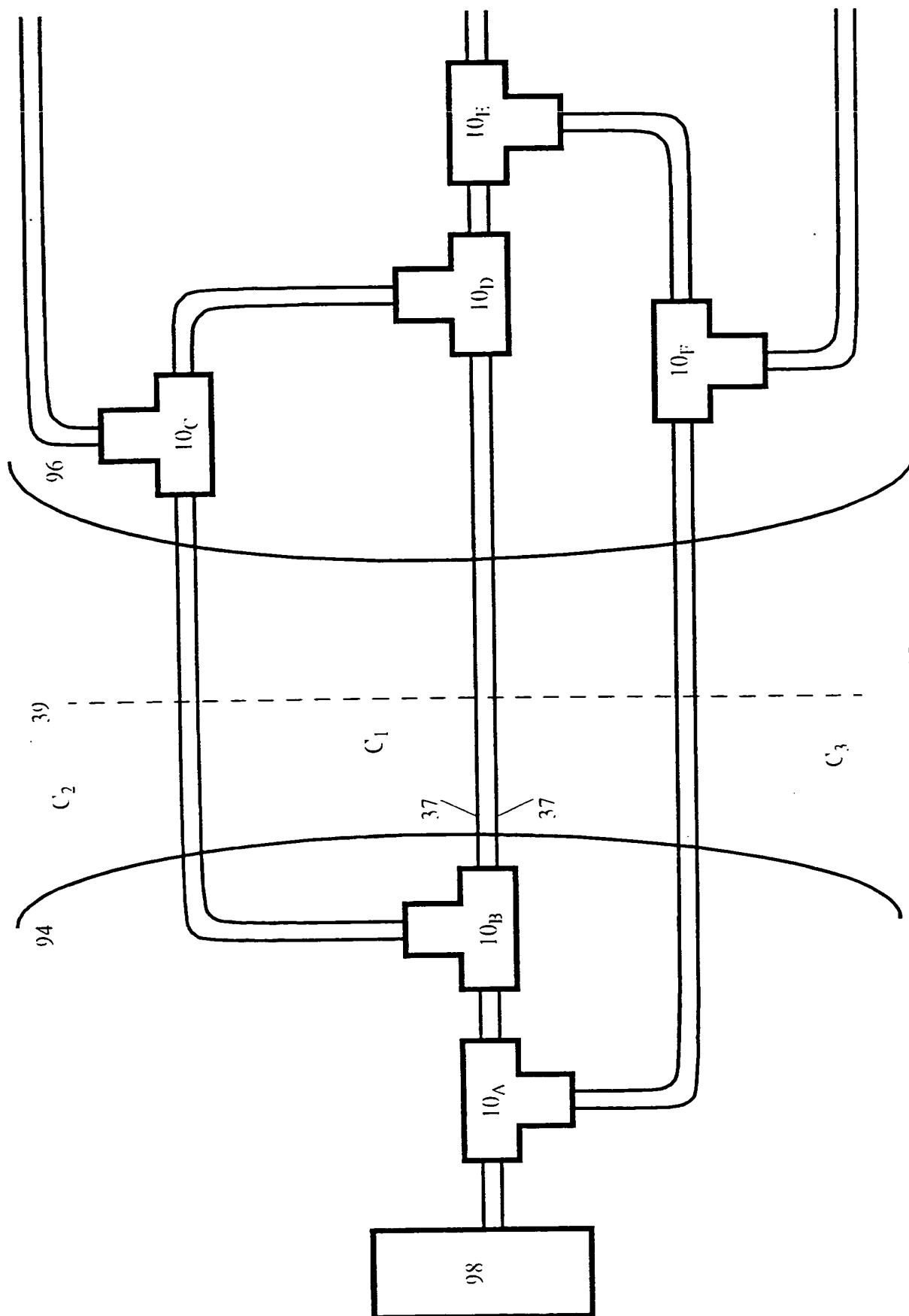


Figure 17

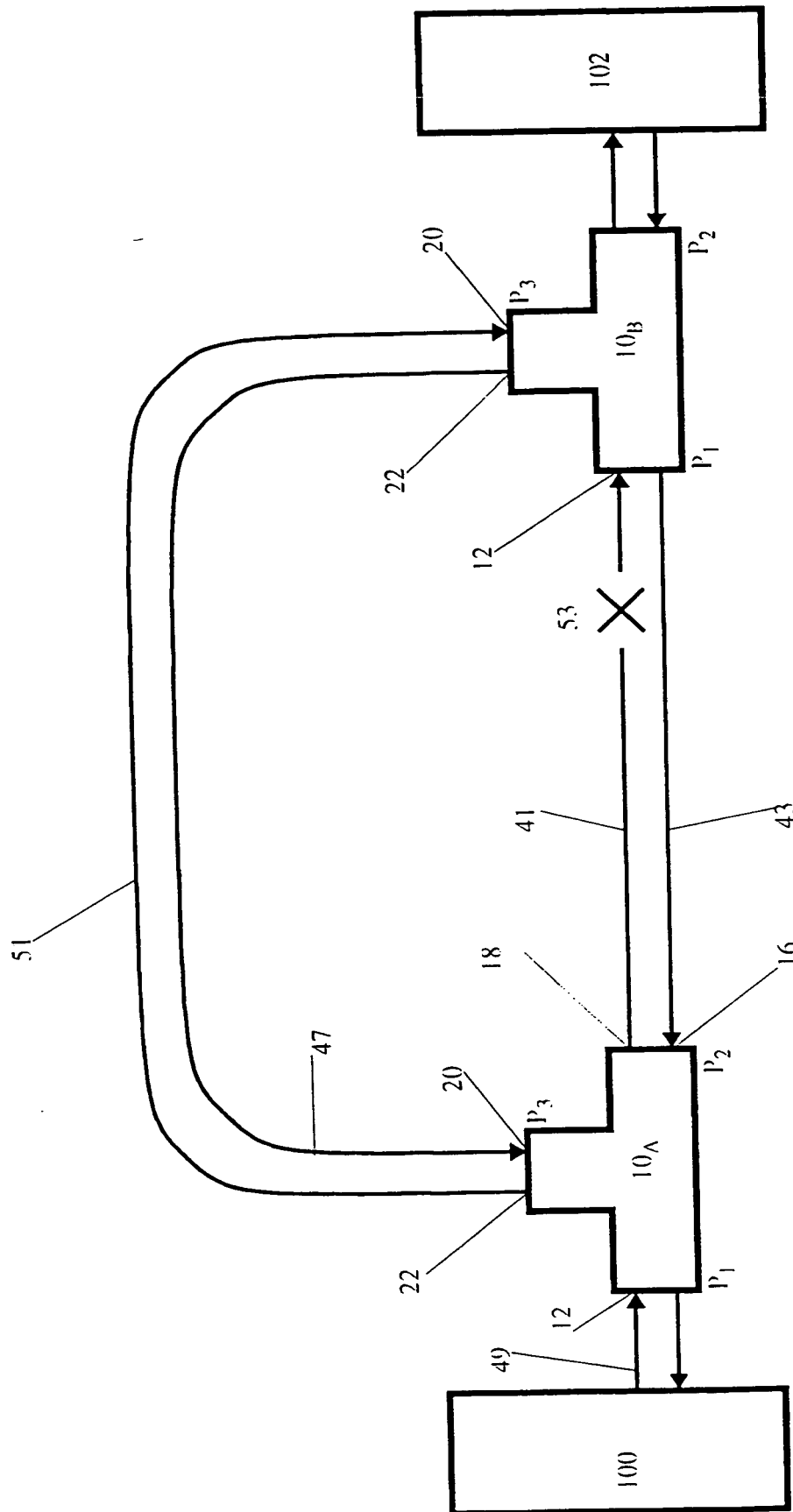


Figure 18

12/14

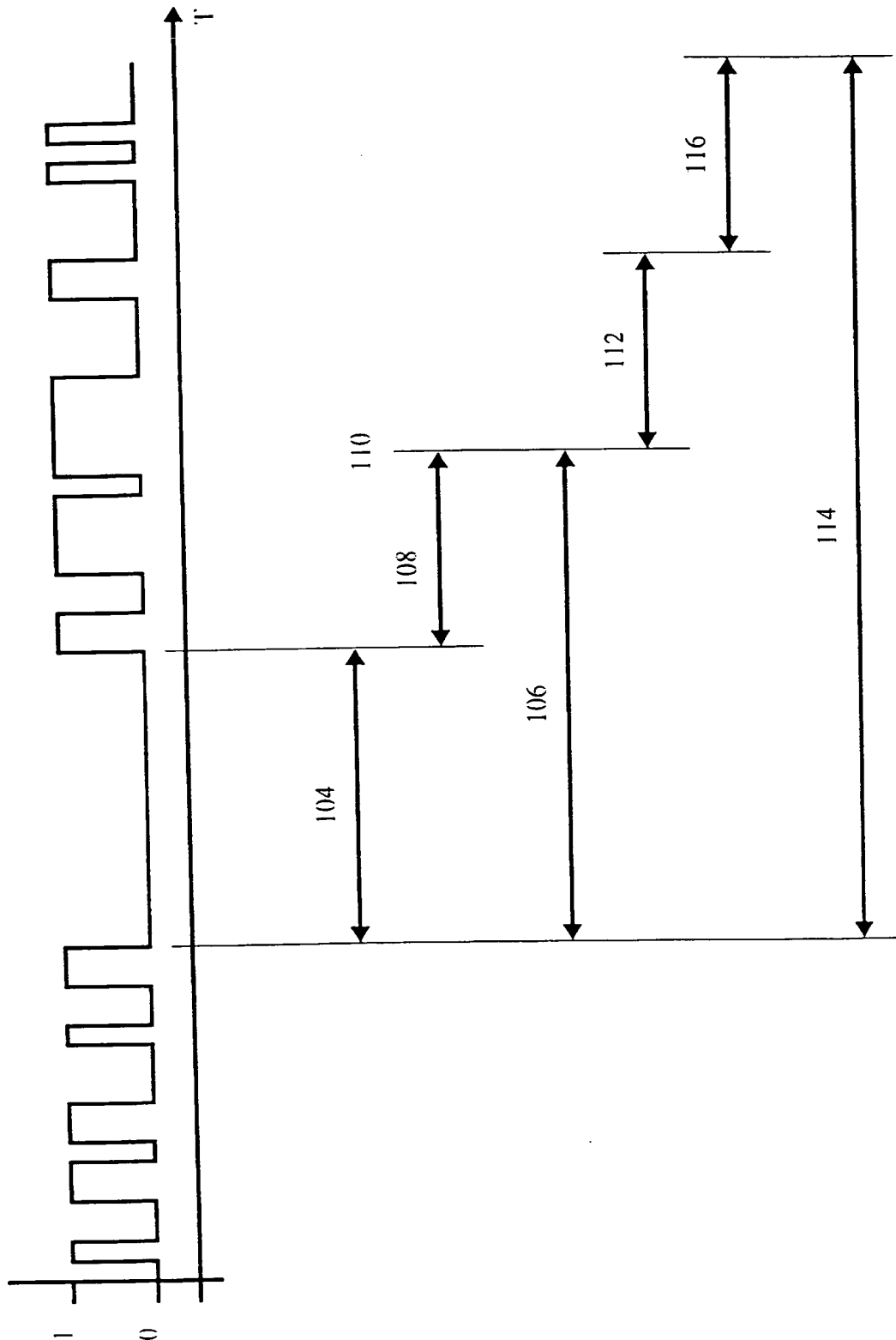


Figure 19

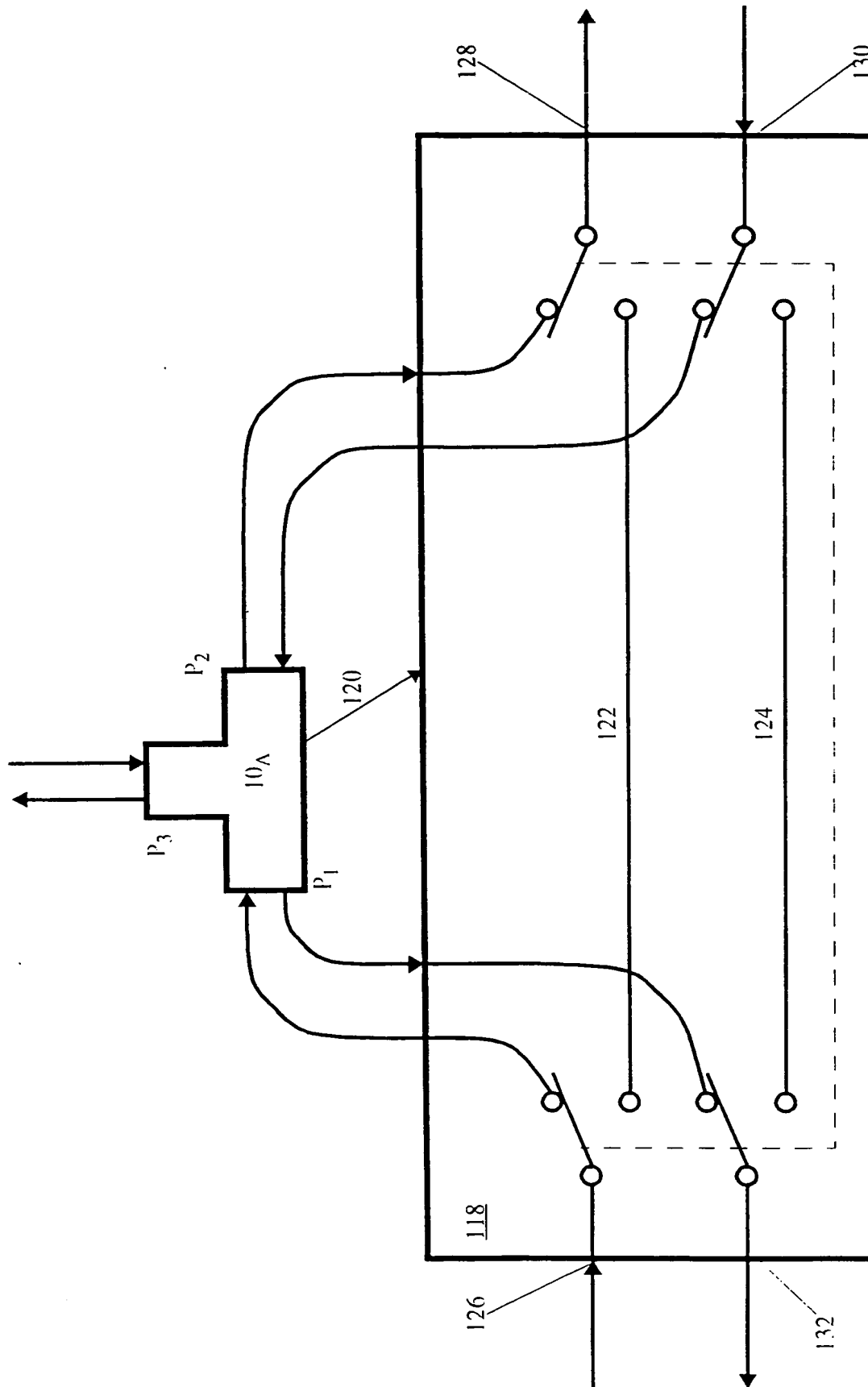


Figure 20

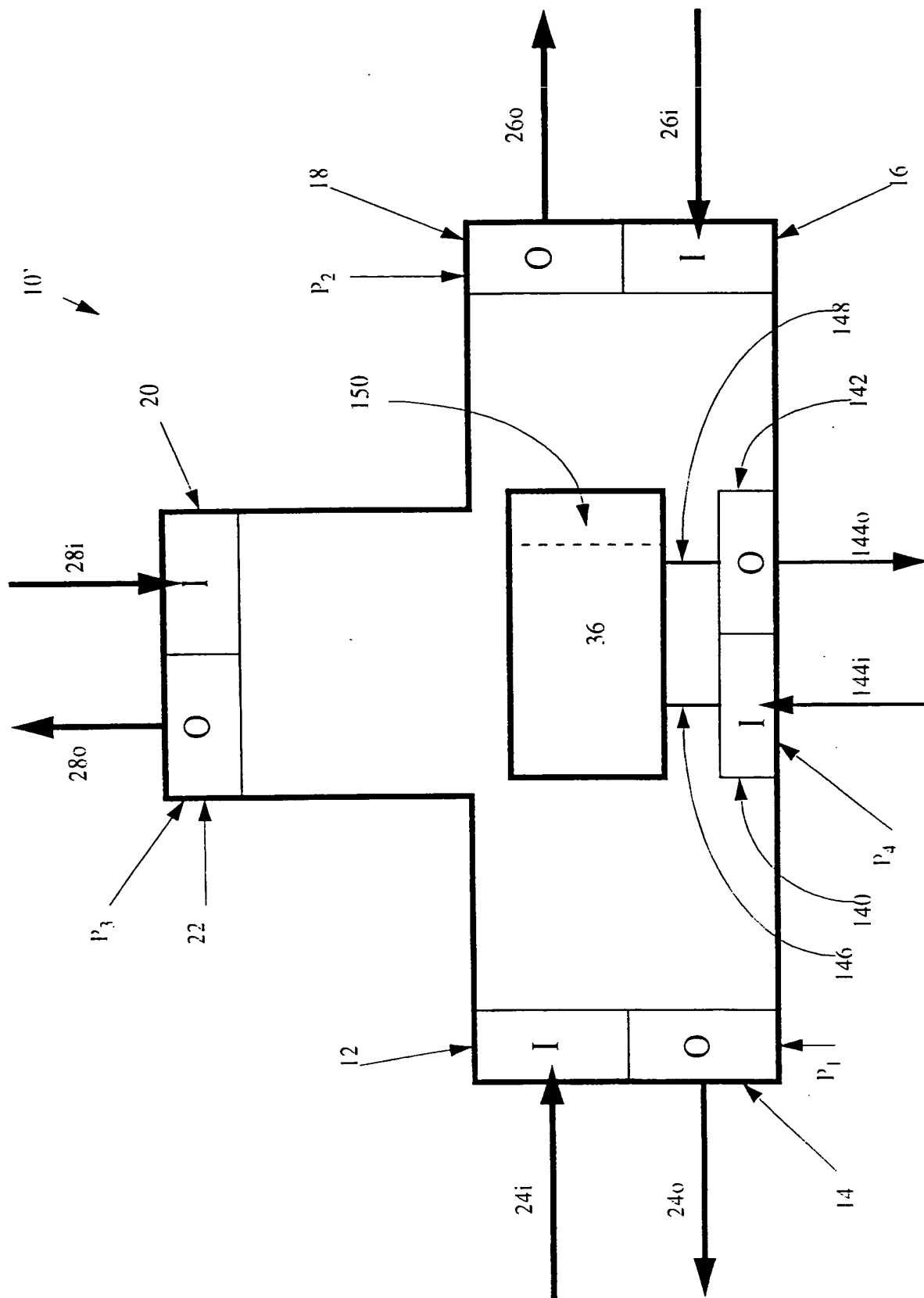


Figure 21

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU00/00998

**A. CLASSIFICATION OF SUBJECT MATTER**Int. Cl. <sup>7</sup>: H04L 12/00; H04Q 11/00; F24D 11/00; F16K 11/00; G05D 7/00; B67D 1/00

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

H04L /IC; H04Q 11/IC; F24D /IC; F16K /IC; G05D /IC; B67D /IC

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
INTERNET

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPAT: switch+ , control+ , valve+ , flow , stream , channel , transfer , detect , divert

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 99/23853 A1 (NOKIA IP, INC.) 14 May 1999, Figure 3 and page 7, line 26 - page 9, line 17.	1
X	WO 99/12381 A1 (OBJECTIVE COMMUNICATIONS, INC.) 11 March 1999 Figure 3 and page 5, line 14 - page 6, line 3.	1
X	US 5610913 A (TOMONAGA ET AL.) 11 March 1997 Figures 15-17 and column 21, lines 34 - 61.	1

☒ Further documents are listed in the continuation of Box C ☒ See patent family annex

<p>* Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>		<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&amp;" document member of the same patent family</p>
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Date of the actual completion of the international search

20 September 2000

Date of mailing of the international search report

25 SEP 2000

Name and mailing address of the ISA/AU

AUSTRALIAN PATENT OFFICE  
PO BOX 200, WODEN ACT 2606, AUSTRALIA  
E-mail address: pct@ipaustalia.gov.au  
Facsimile No. (02) 6285 3929

Authorized officer

*V. J. Samuel*  
SERINEL SAMUEL

Telephone No : (02) 6283 2382

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/AU00/00998

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 4219270 A1 (WOERNER G) 16 December 1993 Whole document	1
A	DE 2942170 A1 (KABEL & METAL GUTEHOFFN) 18 October 1979 Whole document	1

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

International application No.  
**PCT/AU00/00998**

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member			
WO	99/23853	AU	13077/99		
WO	99/12381	AU	96613/98		
US	5610913	EP	674457	CA	2144837 JP 7307745
DE	4219270				
DE	2942170				
					END OF ANNEX



INTERNATIONAL COOPERATION TREATY  
**PCT**  
INTERNATIONAL PRELIMINARY EXAMINATION REPORT  
(PCT Article 36 and Rule 70)

REC'D 08 JUN 2001

WIPO PCT

14

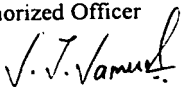
Applicant's or agent's file reference APM:TR:FP13127	<b>FOR FURTHER ACTION</b>	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416).
International Application No. PCT/AU00/00998	International Filing Date (day/month/year) 24 August 2000	Priority Date (day/month/year) 25 August 1999
International Patent Classification (IPC) or national classification and IPC Int. Cl. <sup>7</sup> H04L 12/00; H04Q 11/00; F24D 11/00; F16K 11/00; G05D 7/00; B67D 1/00		
Applicant MARCHANT, Nils		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.
2. This REPORT consists of a total of 3 sheets, including this cover sheet.  
☐ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of sheet(s).

3. This report contains indications relating to the following items:

- |      |                                     |   |
|------|-------------------------------------|---|
| I    | <input checked="" type="checkbox"/> | Basis of the report   |
| II   | <input type="checkbox"/>            | Priority  |
| III  | <input type="checkbox"/>            | Non-establishment of opinion with regard to novelty, inventive step and industrial applicability  |
| IV   | <input type="checkbox"/>            | Lack of unity of invention  |
| V    | <input checked="" type="checkbox"/> | Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement |
| VI   | <input type="checkbox"/>            | Certain documents cited   |
| VII  | <input type="checkbox"/>            | Certain defects in the international application  |
| VIII | <input type="checkbox"/>            | Certain observations on the international application   |

Date of submission of the demand 13 March 2001	Date of completion of the report 29 May 2001
Name and mailing address of the IPEA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized Officer  <b>SERINEL SAMUEL</b> Telephone No. (02) 6283 2382

**I. Basis of the report****1. With regard to the elements of the international application:\***

- ☒ the international application as originally filed.
- ☐ the description,        pages , as originally filed,  
   pages , filed with the demand,  
   pages , received on    with the letter of
- ☐ the claims,        pages , as originally filed,  
   pages , as amended (together with any statement) under Article 19,  
   pages , filed with the demand,  
   pages , received on    with the letter of
- ☐ the drawings,        pages , as originally filed,  
   pages , filed with the demand,  
   pages , received on    with the letter of
- ☐ the sequence listing part of the description:  
   pages , as originally filed  
   pages , filed with the demand  
   pages , received on    with the letter of

**2. With regard to the language, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.**

These elements were available or furnished to this Authority in the following language which is:

- ☐ the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/or 55.3).

**3. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, was on the basis of the sequence listing:**

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

**4. ☐ The amendments have resulted in the cancellation of:**

- ☐ the description,        pages
- ☐ the claims,        Nos.
- ☐ the drawings,        sheets/fig.

**5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).\*\***

\* Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).

\*\* Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report

**V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement****1. Statement**

Novelty (N)	Claims 1-24	YES
	Claims Nil	NO
Inventive step (IS)	Claims 1-24	YES
	Claims Nil	NO
Industrial applicability (IA)	Claims 1-24	YES
	Claims Nil	NO

**2. Citations and explanations (Rule 70.7)**

In the present invention, the switch as claimed detects network link and node failures and as a consequence diverts flow through ports onto external links to avoid those failures. The diversion is achieved without any requirement for any signalling across any link or transmission line in the network and most significantly, the diversion is internal of the switch itself.

-D1 WO 99/23853

-D2 WO 99/12381

-D3 US 5610913

D1 does not claim a detection means for detecting a predetermined characteristic of the flows presented at the input ports and D1 does not internally divert any flow.

D2 does not claim a detection means for detecting a predetermined characteristic of the flows presented at the input ports and D2 does not divert any flow to be presented to any alternative output port.

D3 does not detect predetermined characteristics of an incoming flow from an incoming line. Rather, D3 detects and protects against the failure of an internal line interface units and the failure of internal switch cores as opposed to the failure of external transmission lines.

Therefore claims 1-24 meet the criteria set forth in PCT Article 32(2) for novelty and 33(3) with regard to the requirement of Inventive Step.

# PATENT COOPERATION TREATY

GRIFFITH HACK

15 MAR 2001

PCT

From the INTERNATIONAL BUREAU

To:

MIZZI, Anthony, Paul  
Griffith Hack  
256 Adelaide Terrace  
Perth, Western Australia 6000  
AUSTRALIE

G H I P S MATTER

No. FP13127

1. ~~Rec-13~~
2. ~~APM~~ NOTICE INFORMING THE APPLICANT OF THE COMMUNICATION OF THE INTERNATIONAL APPLICATION TO THE DESIGNATED OFFICES
3. ....

(PCT Rule 47.1(c), first sentence)

Date of mailing (day/month/year) 01 March 2001 (01.03.01)		
Applicant's or agent's file reference APM:FP13127		IMPORTANT NOTICE
International application No. PCT/AU00/00998	International filing date (day/month/year) 24 August 2000 (24.08.00)	Priority date (day/month/year) 25 August 1999 (25.08.99)
Applicant MARCHANT, Nils		

1. Notice is hereby given that the International Bureau has communicated, as provided in Article 20, the international application to the following designated Offices on the date indicated above as the date of mailing of this Notice:  
AU,KP,KR,US

In accordance with Rule 47.1(c), third sentence, those Offices will accept the present Notice as conclusive evidence that the communication of the international application has duly taken place on the date of mailing indicated above and no copy of the international application is required to be furnished by the applicant to the designated Office(s).

2. The following designated Offices have waived the requirement for such a communication at this time:  
AE,AG,AL,AM,AP,AT,AZ,BA,BB,BG,BR,BY,BZ,CA,CH,CN,CR,CU,CZ,DE,DK,DM,DZ,EA,EE,EP,ES,FI,GB,GD,GE,GH,GM,HR,HU,ID,IL,IN,IS,JP,KE,KG,KZ,LC,LK,LR,LS,LT,LU,LV,MA,MD,MG,MK,MN,MW,MX,MZ,NO,NZ,OA,PL,PT,RO,RU,SD,SE,SG,SI,SK,SL,TJ,TM,TR,TT,TZ,UA,UG,UZ,VN,YU.  
The communication will be made to those Offices only upon their request. Furthermore, those Offices do not require the applicant to furnish a copy of the international application (Rule 49.1(a-bis)).
3. Enclosed with this Notice is a copy of the international application as published by the International Bureau on 01 March 2001 (01.03.01) under No. WO 01/15383

## REMINDER REGARDING CHAPTER II (Article 31(2)(a) and Rule 54.2)

If the applicant wishes to postpone entry into the national phase until 30 months (or later in some Offices) from the priority date, a demand for international preliminary examination must be filed with the competent International Preliminary Examining Authority before the expiration of 19 months from the priority date.

It is the applicant's sole responsibility to monitor the 19-month time limit.

Note that only an applicant who is a national or resident of a PCT Contracting State which is bound by Chapter II has the right to file a demand for international preliminary examination.

## REMINDER REGARDING ENTRY INTO THE NATIONAL PHASE (Article 22 or 39(1))

If the applicant wishes to proceed with the international application in the national phase, he must, within 20 months or 30 months, or later in some Offices, perform the acts referred to therein before each designated or elected Office.

For further important information on the time limits and acts to be performed for entering the national phase, see the Annex to Form PCT/IB/301 (Notification of Receipt of Record Copy) and Volume II of the PCT Applicant's Guide.

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland	Authorized officer J. Zahra
Facsimile No. (41-22) 740.14.35	Telephone No. (41-22) 740.83.38